CLIMATE RISK ASSESSMENT OF RENUKA WETLAND, HIMACHAL PRADESH

हिमाचल प्रदेश सरकार

IKI INTERNATIONAL CLIMATE INITIATIVE

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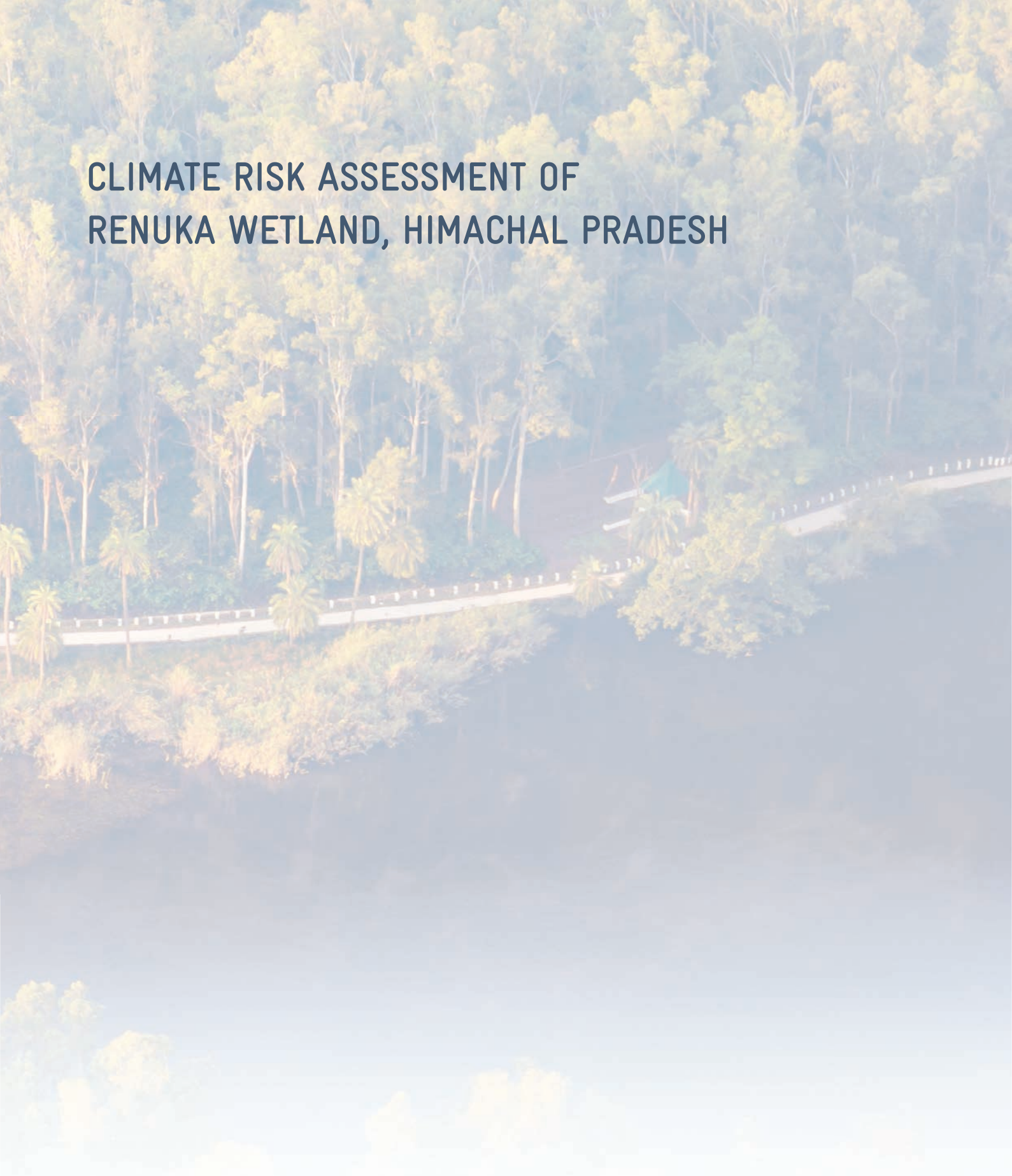

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Climate Change | Biodiversity
Water | Integrated Assessments

25 YEARS
RCDC

MSSRF
Science for Sustainable Development

DPS
DEVELOPMENT OPTION SYSTEM

ABBREVIATIONS AND ACRONYMS

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 BBMB FISHERIES RESEARCH INSTITUTE
CM5A	COUPLED MODEL VERSION 5
CMIP5	COUPLED MODEL INTERCOMPARISON PROJECT VERSION 5
COP	CONFERENCE OF THE PARTIES
CRA	CLIMATE RISK ASSESSMENT
CRZ-I	COASTAL REGULATION ZONE I
CWC	CENTRAL WATER COMMISSION
DEST	DEPARTMENT OF ENVIRONMENT AND TECHNOLOGY
DFO	DIVISIONAL FOREST OFFICE
DFS-GOPA	DAIMLER FINANCIAL SERVICES INDIA PVT. LTD.
DRM	DISASTER RISK ASSESSMENT
EDCs	ECO-DEVELOPMENT COMMITTEES
ESZs	ECO-SENSITIVE ZONES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FARDD	FISHERIES & ANIMAL RESOURCES DEVELOPMENT DEPARTMENT
FECCD	FOREST, ENVIRONMENT AND CLIMATE CHANGE DEPARTMENT
FH & FLCS	FISH HARBOURS AND FISH LANDING CENTRES
FPO	FARMER PRODUCER ORGANISATION
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
IMD	INDIA METEOROLOGICAL DEPARTMENT
INRM	INFLUENTIAL NETWORK RELATION MAP
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IPSL-CM5A	INSTITUT PIERRE SIMON LAPLACE (IPSL) EARTH - CLIMATE MODEL 5A
IUCN	INTERNATIONAL UNION FOR CONSERVATION OF NATURE

JFMC	JOINT FOREST MANAGEMENT COMMITTEES
LAI	LEAF AREA INDEX
LULC	LAND USE AND LAND COVER
MGNREGA	MAHATMA GANDHI NATIONAL RURAL EMPLOYMENT GUARANTEE ACT, 2005
MoEFCC	MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
MPY	MATSYA POKHARI YOJANA
MSSRF	M.S. SWAMINATHAN RESEARCH FOUNDATION
MUY	MATSYJIBI UNAYANA YOJANA
MW	MEGAWATT
NAPCC	NATIONAL ACTION PLAN ON CLIMATE CHANGE
NEWS	NATURE ENVIRONMENT AND WILDLIFE SOCIETY
NPCA	NATIONAL PLAN FOR CONSERVATION OF AQUATIC ECOSYSTEMS
NTFPS	NON-TIMBER FOREST PRODUCTS
PMSBY	PRIME MINISTER SURAKHYA BIMA YOJANA
PRDWD	PANCHAYATI RAJ AND DRINKING WATER DEPARTMENT
PRECIS	PROVIDING REGIONAL CLIMATES FOR IMPACTS STUDIES
RAINFOREST CRC	CO-OPERATIVE RESEARCH CENTRE FOR TROPICAL RAINFOREST ECOLOGY AND MANAGEMENT
RCDC	REGIONAL CENTRE FOR DEVELOPMENT CO-OPERATION
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
RIDF	RURAL INFRASTRUCTURE DEVELOPMENT FUND
RIS	SITES INFORMATION SERVICE
SAPCC	STATE ACTION PLAN ON CLIMATE CHANGE
SEP	SELF-EMPLOYMENT PROGRAMME
SLR	SEA LEVEL RISE
THI	TEMPERATURE HUMIDITY INDEX
UK	UNITED KINGDOM
UN	UNITED NATIONS
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

Executive Summary

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

RENUKA WETLAND

The Renuka wetland is located at an altitude of 645 m, in Sirmaur district, of Himachal Pradesh. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as it is broad and covers an area of approximately 30 ha. The wetland's 358 ha catchment area includes about 250 ha of mostly sub-tropical deciduous forest of broad leaf species, bamboos, palms and other wild plants. The wetland receives water primarily from the South-West monsoon, through four springs and seasonal streams, which also bring large quantities of silt and debris from poorly vegetated areas of the catchment.

METHODOLOGY FOR THE CLIMATE VULNERABILITY ASSESSMENT AT THE RENUKA WETLAND

The climate vulnerability assessment at the Renuka Wetland was conducted using the Climate Change Adaptation and Mitigation (CAM) method, developed by ICEM as a flexible tool and process for climate change adaptation and mitigation planning and implementation, tailored specifically to the Asia-Pacific region. 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 based on international best practices. The intention is to have the vulnerability assessment and adaptation planning process integrated into the regular site management planning cycle.

Photo credit: JoblessStudios.GIZ

The CAM method has three main phases: (1) impact and vulnerability assessment, (2) adaptation planning, and (3) implementation and feedback. The GIZ and ICEM team worked with site managers and local stakeholders to apply the CAM method to establishing the evidence base for robust and well-informed site management. The CAM method considered four factors (exposure, sensitivity, impact and adaptive capacity) in assessing the vulnerability of the target system and its components to climate change, based on an understanding of the threats posed by climate change.

BASELINE CONDITIONS AT THE RENUKA WETLAND

The target assets of the Renuka Wetland considered in the vulnerability assessment include the freshwater habitats of the shallow water margins to the Lake, which are important feeding grounds for the migratory birds, and the sandy/muddy banks on which the turtles nest. These areas are experiencing the pressure of sedimentation, and habitat conditions are changing rapidly. The aquatic grasses that grow within these shallow water areas provide feed for the migratory duck species (especially the Mallard), turtles and fish. The turtles are an important species. They were initially reported as the Critically Endangered *Batagur kachuga* but are probably Endangered *Nilssonia* spp. according to Forest Department officials. The second target species selected for the assessment is the Endangered Golden Mahseer *(Tor putitora),* which is the most sensitive of the 19 fish species recorded in the Lake. A cooler water species, the Golden Mahseer relies upon stony substrates in the streams flowing into the lake for spawning. The lake is also an important tourist destination for religious pilgrims coming to the temple, especially during the religious fair in November each year and recreational visitors coming to experience the lake and its wildlife, including boating and the mini zoo. The catchment around the lake is also identified as a critical asset, with rainfall refreshing the four ground water springs and maintaining their water levels throughout the year. The forest cover in the catchment is important for ensuring soil stability and recharging the ground water.

Photo credit: JoblessStudios.GIZ

CLIMATE CHANGE AT THE RENUKA WETLAND

Projections of the precipitation and temperature by the 2050s at the Renuka Wetland were modelled against a baseline period of 1960-1990, using the ensemble mean of three selected GCMs (CCSM4, HadGEM2-ES and MIROC-ESM) for the RCP 8.5 scenario.

The total precipitation is projected to increase by 224.9 mm (12.6%) during the SW monsoon (June –September), from 1789.5 mm to 2014.4 mm by the 2050s. The precipitation is projected to decrease during the NE monsoon by 12.3 mm or 9.2%, in winter by 11.3 mm or 7.9% and in summer by 7.1 mm or 6.0%.

The temperature is projected to increase by 2.1°C to 3.3°C by the 2050s. The most significant increase is projected for summer (March – May), 3.3°C, from 30.9°C to 34.2°C. The least increase is projected for the SW monsoon (June – September), 2.1°C, from 31.1°C to 33.2°C. Temperatures during the NE monsoon (October – December) and winter (January – February) are projected to increase by 2.8°C, from 24.2°C to 27.0°C, during the NE monsoon and from 19.2°C to 22.0°C in winter.

Higher rainfall during the rainy season may threaten the Ramsar Site with a higher risk of flash flooding and riverine floods, along with increases in sedimentation. Lower rainfall in the dry season may cause intensive droughts in the surrounding areas and negatively affect habitats in the Ramsar Site. In addition, the higher temperatures in the hot season may cause a higher risk of forest fires.

IMPACT AND VULNERABILITY ASSESSMENTS

The results of the climate change vulnerability assessment indicate that climate change is already impacting the Renuka wetland ecosystems and that those effects, direct and indirect, will become more pronounced in the decades leading up to 2050. Changes in the rainfall intensity and frequency of extreme climatic events such as droughts and flooding will lead to negative effects on Renuka species and habitats and on the catchment area of the lake. Changes in the air temperature and precipitation have direct effects on the physical, chemical, and biological characteristics of the lake. Climate change has the potential to change the physical structure of the Renuka ecosystems and lead to significant alteration to the aquatic and terrestrial biota and ecosystem services.

SUMMARY OF VULNERABILITY SCORES FOR RENUKA WETLAND

With climate change, increased rain intensity is leading to increased sedimentation in the lake due to erosion and runoff. Too much sediment deposition can bury habitats and impact benthic creatures. The silt and increased nutrient level are accelerating the lake’s eutrophication, and the projected increase in temperature can facilitate algal blooms that produce harmful toxins that can kill aquatic life. The increased water temperature can affect fishes directly by affecting their physiology, growth and, indirectly, behaviour, including spawning patterns. With the accelerated decrease in the lake size and increase in the area of dry banks, the habitat of various aquatic creatures and migratory birds is under threat. The increased organic load may also impact the habitat of various aquatic species, endangering their long-term survival. A summary of the vulnerability assessment of the six critical assets in the Renuka Wetland in the context of a range of projected climate changes is presented in the following matrix:

Threats	Catchment- Surrounding Hillsides					Habitats					Golden Mahseer					Bengal Roofed Turtle					Aquatic grasses					Recreation, 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–Sep)	H	H	H	VL	VH	H	H	H	VL	VH	H	H	H	M	H	VH	VH	VH	VL	VH	H	H	H	L	H	H	H	H	L	H
Decrease of rainfall during dry season (Oct-May)	M	M	M	VL	H	L	M	M	M	M	L	L	L	L	M	H	H	H	L	H	M	M	M	H	M	M	M	M	M	M
Temperature																														
Increase of temperature during Winter (Jan-Feb)	H	H	H	L	H											H	H	H	L	H	H	H	H	L	H	M	M	M	L	M
Increase of temperature during Summer (Mar-May)	H	VH	VH	L	VH	H	H	H	L	H	H	H	H	L	VH	L	L	L	L	M	H	H	H	L	H	L	L	L	H	L
Increase of temperature during Monsoon (Jun-Sept)	M	M	M	M	M	M	M	M	L	M	M	M	M	L	M	M	M	M	L	M	M	M	M	L	M	H	H	H	L	H
Increase of temperature during Post-Monsoon (Oct-Dec)	H	H	H	L	H	H	H	H	L	H	M	M	M	L	M	M	M	M	L	M	H	H	H	L	H	L	L	L	L	L
Extreme events																														
Flash Flooding	VH	VH	VH	VL	VH	H	H	H	VL	VH	H	H	H	L	H	VH	VH	VH	VL	VH	H	H	H	L	H	H	H	H	L	H
Drought	H	H	H	VL	VH	H	H	H	L	H	H	H	H	L	H	H	H	H	VL	VH	H	H	H	L	H	H	H	H	L	H
Fires	VH	VH	VH	VL	VH						H	H	H	L	H															

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

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

The projected climate changes are likely to impact the forests in the catchment, resulting in changes in species composition and biodiversity. For example, Sal and Shisham, the two major forest species in the Renuka Wetland catchment, are considered vulnerable to climate change. Various studies conducted across the Himalayan ranges have reported a reduction of their survival rate and regeneration abilities as the impact of climate change on these tree species. Climate-related extreme weather such as high temperatures will also increase the evapotranspiration and impact soil moisture and biodiversity.

Ground water resources may be affected as high-intensity rains lead to runoff from the slopes with very little percolation, especially in a degraded, partially deforested catchment. Ground water levels will tend to fall during droughts and prolonged dry seasons.

ADAPTATION PLANS

A variety of adaptation options are considered for each of the target assets addressing the principal climate change threats. Many of these options are designed to (1) decrease the soil erosion in the catchmen, 2) trap or divert sediment from reaching the lake and thus changing the habitat conditions, and (3) removing sediment build-up in the lake through de-silting. Thus, reforestation of gaps in the forest, selection of climate resilient native tree species and removal of invasive species are included as options to decrease soil erosion and to increase ground water recharge, which is important for maintaining water levels in the lake throughout the year.

The management of the threats of sedimentation and filling up of the lake depends upon the adaptation measures in the catchment, but also on protection against increasing water temperatures through planting of riparian shelter belts and protection of the incoming streams. In the event of extreme events, provision of alternative food sources for the fish and turtles may be considered.

Religious and recreational tourism are the main cultural ecosystem services of the Ramsar Site and, the adaptation options proposed include diversification of tourism activities away from the site to reduce visitor pressure and to establish recognised zoning of accommodation and facilities to manage encroachment on the natural areas. Improvement of the wastewater treatment and solid waste management of the tourism site will be necessary to reduce the risks of water pollution and eutrophication of the lake, which will be aggravated by increasing temperatures.

RECOMMENDATIONS FOR THE MANAGEMENT OF THE SITE AND STAKEHOLDERS

The categorisation of the various adaptation options as short, medium and longer-term actions is presented. This phased adaptation strategy will require feasibility assessment, design and planning and budgeting of each measure to be incorporated into the management plan for the site. One of the main institutional issues for site management is the differing responsibilities of stakeholders – Renuka Vikas Board, Wetland Authority, Wildlife and Forest departments, the tourism stakeholders and the temple ashrams. The main recommendation is to establish a co-ordination platform to consider climate change threats and agree on the adaptation measures to be undertaken to make the site more resilient, as a matter of mutual interest to all stakeholders.

1 INTRODUCTION

1.1 Background

Wetland systems are highly vulnerable to climate change. As climatic patterns become more extreme, there may be pronounced effects for wetlands 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 co-operation project *Wetlands Management for Biodiversity and Climate Protection, i*mplemented by the Ministry of Environment, Forest and Climate Change (MoEFCC), in partnership with GIZ. The four Ramsar sites are **Renuka Wetland, Pong Dam Lake, Bhitarkanika Mangroves** and **Point Calimere Wildlife and Bird Sanctuary.** These four sites, namely upland lakes and reservoirs in Himachal Pradesh and 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 assignment to work with site managers and local stakeholders to conduct climate change vulnerability assessment and adaptation planning aims to build a comprehensive adaptation strategy into management plans and budgets, leading to enhanced resilience of the four wetland sites through more effective adaptive management. By considering sites in these two distinct ecosystems, the assessments can also serve as demonstrations of a methodology that can be replicated in other wetland areas across India.

This final report on the climate risk assessment of the Renuka Wetland is one of four linked reports on the four Ramsar Sites. This report contains two chapters that are common to all the reports, which are followed by chapters with the specific findings on the Renuka Wetland.

- **Chapter 1** presents project background and operational information.
- **Chapter 2** describes the methodology used for climate risk assessments at the four Ramsar Sites, including methods of vulnerability assessment, adaptation planning and stakeholder consultations.
- **Chapter 3** describes the baseline conditions at the Renuka Wetland
- **Chapter 4** provides the climate change profile of the site.
- **Chapter 5** synthesises and presents results from the vulnerability assessments of the target assets, and the detailed VA matrices are annexed.
- **Chapter 6** develops the adaptation plans for the site from the annexed adaptation matrices of the target assets.
- **Chapter 7** 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 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 Wetland, Pong Dam Lake, Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary.
- Proposing measures that help reduce the vulnerability of wetlands to changing climate by mitigating the adverse change, minimising exposure, reducing sensitivity and adapting to the changes.

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

1.3 Overview of the four Ramsar Sites

1.3.1 Renuka Wetland

The Renuka wetland (longitude 77°27′E, latitude 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 leading to an adjoining pond, Parashuram Tal, which ultimately drains into the River Giri through a small channel. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as it is broad, having an area of approximately 30 ha. Its 358 ha catchment area includes about 250 ha of mostly sub-tropical deciduous forest of broad leaf tree species, bamboos, palms and other wild plants. he Renuka Wetland Management Action Plan (2013 – 2022) lists 103 bird species belonging to 38 families at the site, with 66 resident species. Renuka Wetland is also home to freshwater turtles.

The wetland receives water primarily from the South-West monsoons, which feed four permanent springs and 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.

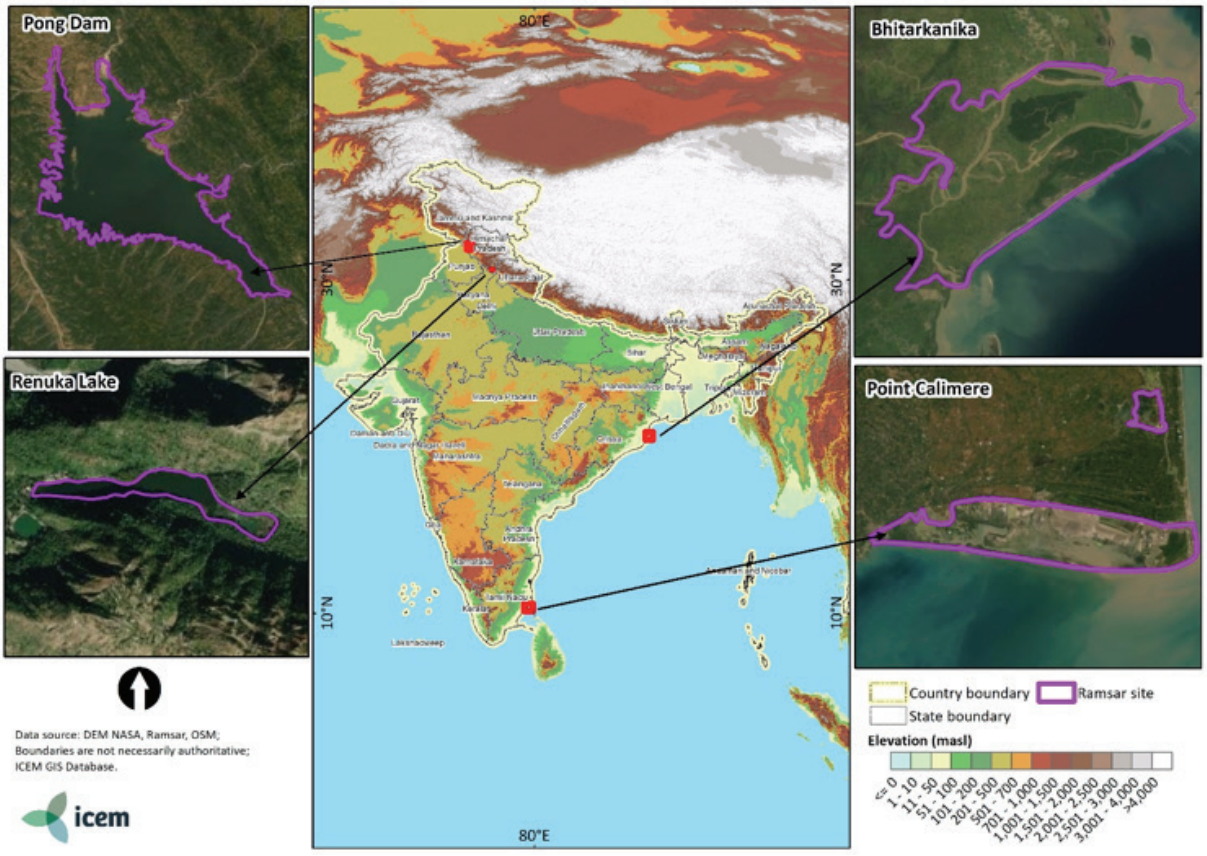

Figure 1 *Locations of the four Ramsar Sites targeted for vulnerability assessment and adaptation planning*

1.3.2 Pong Dam Lake

The 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. Some 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 entire 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 Lake is home to about 423 species of bird, 18 species of snake, 90 species of butterfly and 24 mammal species (Malik & Rai, 2019). According to the 2020 report produced by wildlife officials, the number of birds has gone up marginally compared to 2018.

1.3.3 Bhitarkanika Mangroves

Bhitarkanika Mangroves, located in Odisha State, India, covers about 65,000 ha on the east coast of India (20°39′N, 086°54′E) (Figure 1). It was designated as a Ramsar Site in 2002. This wildlife sanctuary is one of the finest remaining patches of mangrove forest in the region. The site is visited annually by about 500,000 Olive Ridley sea turtles, which makes it the world's largest mass nesting beach. It is a habitat for bird nesting and breeding, with 280 species of bird, and the site contains one of the largest heronries in Asia. Bhitarkanika Mangroves has the highest density of Saltwater Crocodiles (*Crocodylus porosus)* in the country, supporting a population of 1700 individuals. It is one of the most diverse mangrove ecosystems in India, with 70 mangrove species. The Bhitarkanika Mangroves forests provide vital protection for millions of people from frequent devastating cyclones and tidal surges. Currently, this area also supports 250,000 inhabitants in 410 villages who are mainly dependent on agriculture, fishing and aquaculture.

1.3.4 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 declared as a Ramsar Site in 2002. The total area of the wetland complex is 38,500 ha (Figure 1). The 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)*[1]. The sanctuary serves as the breeding ground or nursery for many commercially important species of fish, as well as for prawns and crabs. Many fishers and farmers are dependent on the wetland for their livelihoods. A spread of *Prosopis sp.,* 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 for this assessment followed the steps of the CAM (Climate Change Adaptation and Mitigation) method, which has been developed by ICEM as a flexible methodology to climate change adaptation and mitigation planning and implementation, adapted specifically to the 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.

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

[2] The Ramsar Information Sheet stated that the catchment area for Renuka lake was 500 ha. Recent hydrological analysis

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

- Impact and vulnerability assessment
- Adaptation planning
- Implementation and feedback

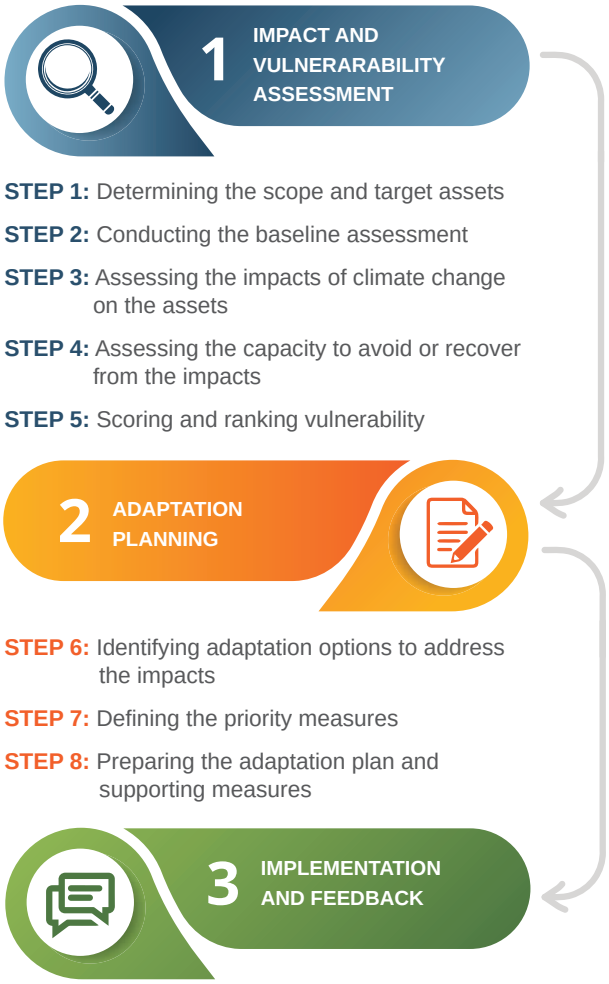

***Figure 2** Phases and steps of CAM*

For the vulnerability assessment and adaptation planning, the expert team used the CAM method to undertake a threat analysis for 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 in detail 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 geared towards the important phases of the assessment and identification of adaptation measures, namely:

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

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

Table 1 *Capacity 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 of climate change risks and adaptation measures were included at the stakeholder consultation workshops where the vulnerability assessments and adaptation planning are presented and discussed. Consultation workshops were conducted during the field missions to the Ramsar Sites and during the virtual consultation process.
Preparing a climate risk assessment framework and guidance document for wetlands incorporating the learnings from the assessment	Various documents will be prepared and published, including: • CAM methodology guide for training and application at other Ramsar Sites • Climate risk profile and vulnerability assessment for four wetland sites • EbA action plan recommendations for each wetland site

2 BASELINE ASSESSMENT FOR RENUKA WETLAND

2.1 Site description

The Renuka wetland (longitude 77°27′E, latitude 300°36′N) is located at an altitude of 645 m, in the Sirmaur district of Himachal Pradesh (Figure 3). The wetland comprises a large oblong-shaped lake with a small outlet to an adjoining pond, Parashuram Tal, which ultimately drains into the river Giri through a small channel. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as it is broad, having an area of approximately 30 ha. Its 358 ha catchment area[2] includes about 250 ha of mostly sub-tropical deciduous forest with bamboos, palms and other wild plants (Figure 4). The wetland receives water primarily from the SW monsoons through seasonal streams, which also bring large quantities of silt and debris from poorly vegetated areas of the catchment. There are four permanent springs maintaining the water level in the lake throughout the year, and a perennial underground seepage water supply, possibly from the upper Giri river, has also been reported.

[2] The Ramsar Information Sheet stated that the catchment area for Renuka Wetland was 500 ha. Recent hydrological analysis has revised that estimate downwards to 358 ha. (Renuka Hydrogeological Assessment 2020)

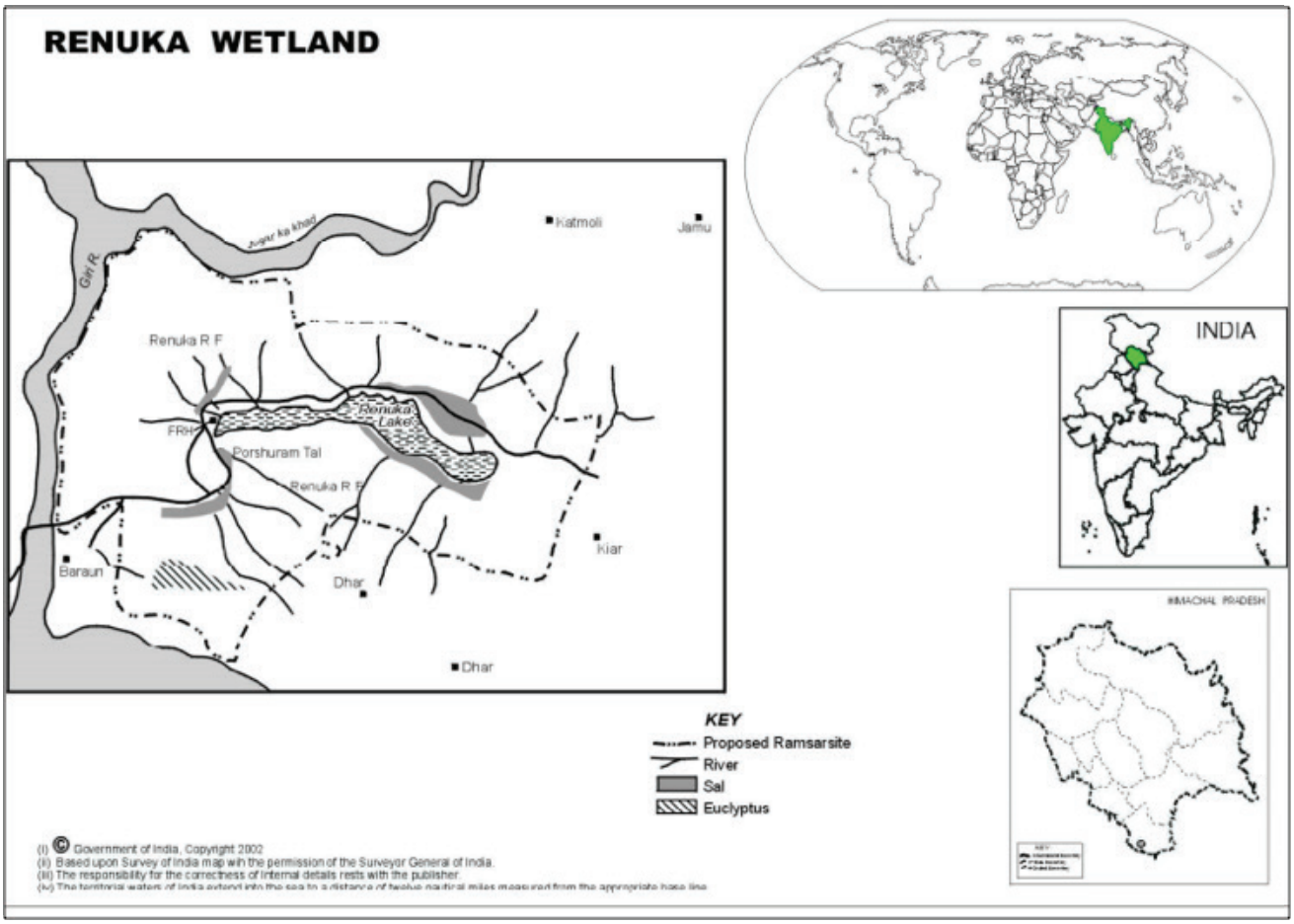

Figure 3 *Renuka wetland map*
(Source: https://rsis.Ramsar.org/)

The lake water is alkaline at the surface, with a pH value ranging between 8.0 and 8.2, and slightly acidic to alkaline at the bottom, with a pH value between 6.9 and 7.4. During the stagnant period, the mean values of the temperature, transparency and dissolved oxygen remain at 16.5°C, 204 cm and 7.6 ppm, respectively. The lake water is hard due to addition of calcium and magnesium from leaching of the dolomite formation of the catchment. The maximum water depth in the lake is 13 m. The total catchment area is about 358 ha. The catchment is covered in sub-tropical vegetation. The outlet of the wetland is towards Parshuram Tal (pond), from where the water flows toward the Giri river in the west. The annual rainfall is 1500 – 2000 mm, and the monsoon brings 70% of the rainfall from July to September. The maximum and minimum temperatures recorded in the area are 44°C (in summer) and 5°C (in winter), respectively.

Geologically, the area represents a part of the main range of the Lesser Himalaya. The rocks belonging to the Krol formation are exposed in the catchment. Between the two ridges, the lake has an East–West orientation. The southern slopes are steep, whereas the northern side is characterised by gentle slopes from Jammu Ka Tibba, in the north, to the highest point (1591 m) in the catchment. The basin of Renuka Wetland is believed to be an abandoned channel of the Giri river, presently flowing west of the lake but which in the past flowed along the length of the Renuka Wetland. The river may have been blocked by a massive landslide, forming a lake upstream. As a result, the river Giri once occupied the course of its tributary, the river Jalal. Hydrologically, the catchment of the wetland is drained by 21 small and big streamlets, which receive water mainly during the rainy season. The perennial source of water of the lake comes from internal springs, which emanate from fractures and faults. The limestone and dolomite geology of the area encourages the formation of springs.

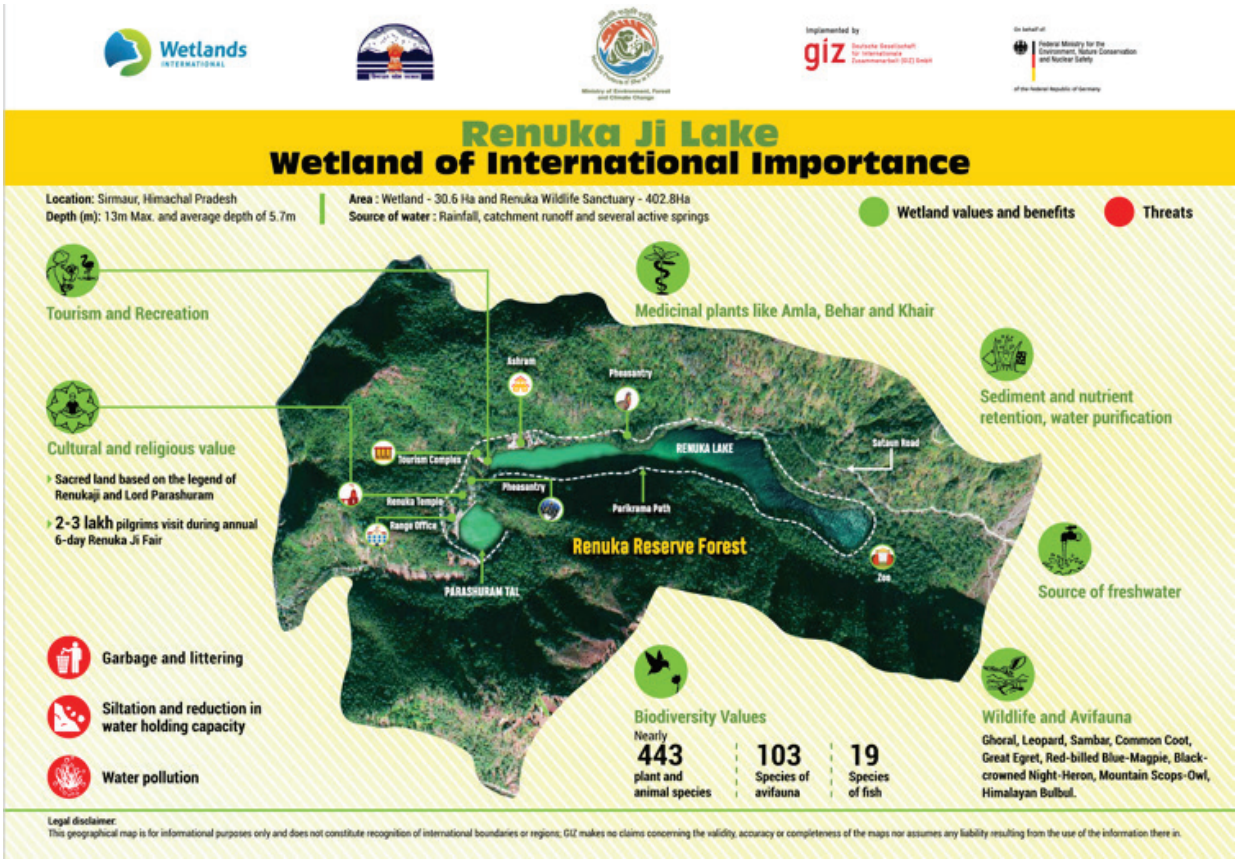

Figure 4 *Poster of Renuka Wetland*
(Source: Indo-German Biodiversity Programme, Biodiversity conservation)

2.2 Identification of target assets

From the findings of the field missions and stakeholder consultations, six critical assets were selected for further detailed assessments (Table 2). The target assets were selected using a simple selection scoring process (Table 3), as part of the overall vulnerability assessment of the site.

Table 2 *Target assets of the Renuka Wetland vulnerability assessment*

Target asset name		Description
Key habitats	Catchment – surrounding hillsides	Seasonal streams and four permanent springs, hillsides covered with Sal forest at the northern extreme of its range. Spread of invasive species – *Lantana camara* and *Adhatoda vesica.*
	Shallow water on the sides providing a habitat for birds and dry bank areas providing nesting ground for turtles	During winter dry banks provide the nesting ground for turtles. The shallow water provides the breeding ground for migratory birds.
	Aquatic grasses growing in and around the lake	The aquatic flora providing the food for migratory birds include *Phalaris aquatica, Typha elephantina* and *Acorus calamus*

Target asset name		Description
Keystone species	Golden Mahseer	Golden Mahseer, Tor *putitora* Hamilton, one of the largest freshwater fish of the Indian sub-continent, inhabits mainly Himalayan rivers in the foothills. Endangered species, migrates up streams and rivers to spawn in the monsoon.
	Turtles	Species recorded in Renuka are the Critically Endangered *Batagur kachuga* and the Endangered *Nilssonia gangetica,* Indian Softshell Turtle, and *Nilssonia hurum*, the Indian Peacock Softshell Turtle. The Wildlife Department indicates that B. *kachuga* is no longer present.
Ecosystem services	Recreation, tourism, religious tourism	Religious tourism and yearly fair are big attractions. The wildlife sanctuary, mini zoo and boating are other tourist attractions.

Table 3 *Scoring for asset selection*

Criterion	Question	Catchment	Key habitats	Keystone Species	Ecosystem services
Representativeness	To what extent is the habitat, species or ecosystem service representative of the site?	4	4	5	3
Ecological significance	To what extent is the habitat, species or ecosystem service significant for ecological processes?	5	3	4	4
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?	5	4	4	4
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 with changing conditions?	5	5	5	4
Non-climate threats	To what extent is the asset threatened by non-climate challenges or is the focus for management?	5	4	4	5
Availability of data	To what extent is data available on the habitat area/condition, species populations, or ecosystem service (for the site or region)?	3	2	2	2
Total	**Sum the scores for each asset**	**27**	**22**	**24**	**22**

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

2.2.1 Catchment and hydrology – surrounding hillsides

The biodiversity of the Renuka Wetland catchment is rich. The southern slopes are steep, whereas the northern side is characterised by gentle slopes. The hills that surround the lake on its northern and southern sides are covered with dense sub-tropical forests, and the vegetation is dry deciduous. The eastern flank of the Lake is a less vegetated catchment area. The steep slopes surrounding the Renuka Wetland (50° to 55°) are the major determinant of the increasing sedimentation rate. Hydrologically, the catchment of the wetland is drained by 21 small and big streamlets, which receive water mainly during the rainy season. The lake receives most of the sediment from the catchment through streams and surface erosion.

The total catchment area of the lake is covered with sub-tropical vegetation. The entire catchment area is a reserve forest and has been declared a wildlife sanctuary. According to forest types classification by Champion and Seth, Renuka forest fall under group 5B/C2 i.e. dry mixed deciduous forest and group 5/051 i.e. dry Sal forest. The area forms northern limit of natural Sal Forest which itself is limited to Badaun Dhar. Sal is found mixed with its major dry deciduous associates, including overwood trees *Terminalia tomentosa, Shorea robusta* (Sal), *Moringa pterygosperma, Ougeinia dalbergioides, Cassia fistula* (Amaltas), *Bauhinia variegata* (Kachnar), *Ficus palmata, Ficus religiosa* (Anzir), *Bambusa arundinacea, Phoenix* spp., *Salix tetrasperma* and *Dalbergia sissoo.* The area also supports good populations of Sambar, Barking Deer and Goral.

2.2.2 Key Habitats

Shallow water on the sides providing a habitat for birds and dry bank areas providing nesting ground for turtles
Renuka Wetland itself is the habitat of many wildlife species, including many resident and migratory birds. The aquatic habitat is shrinking. The depth and area of the lake have shrunk considerably. In a study conducted by the Geology Department, Punjab University, it was found that the lake is gradually shrinking, and silting is increasing at a rate of 3.3 mm annually.

There are two distinct habitats present in the Renuka wetland – the shallow water habitat (of birds) and the dry bank areas (which provide a nesting ground for turtles). The shallow water habitat for migratory birds is created by the silt brought down by the seasonal streams, and as the silt builds up it, creates the dry bank areas, providing a nesting ground for turtles.

Initially, the silt brought down to the lake proved beneficial for the migratory birds. Now, excessive rainfall is leading to increasing siltation filling shallow water areas and eventually turning them into dry banks, reducing the extent of the shallow water habitat. Since the lake size is small, so is the carrying capacity, resulting in higher rates of eutrophication, and increasing sediment loads will eventually fill the lake completely, with progressive expansion of the dry banks narrowing down the aquatic habitat for migratory birds and turtles.

The Renuka Wetland Management Action Plan (2013 – 2022) notes that 103 bird species belonging to 38 families have been identified, with 66 species of resident bird, e.g., Crimson-Breasted Barbet *(Megalaima haemacephala),* Red-Vented Bulbul *(Pycnonotus cafer),* Robin *(Saxicoloides fulicata),* Minivet *(Pericrocotus flammeus)* and House Swift *(Apus nipalensis).* Nineteen species of migratory bird are sighted during winter, including the Lapwing *(Vanellus indicus),* Egret *(Egretta garzetta),* Mallard *(Anas platyrhynchos)* and Pond Heron *(Ardeola grayii).*

Renuka is also home to freshwater turtles, and feeding fish and turtles is one of the tourist attractions. The Renuka Management Plan 2013/14 – 2022/23, identifies the Bengal Roofed Turtle, *Batagur kachuga,* which is classified as Critically Endangered on the IUCN Red List. Also, a recent publication by the Zoological Survey of India notes the presence of *B. kachuga* at Renuka Wetland[3]. However, discussions with local stakeholders during this study indicated that this species was not present, and the turtles at Renuka Wetland are probably *Nilssonia gangetica,* the Indian Softshell Turtle, and *Nilssonia hurum,* the Indian Peacock Softshell Turtle, which are both classified as Endangered on the IUCN Red List.

[3] Chandra, K., Bharti, D., Kumar, S., Raghunathan, C., Gupta, D., Alfred, J.R.B. and Chowdhury, B.R. 2021. Faunal Diversity in Ramsar Wetlands of India, pp. 1–292 (Jointly Published by the Director, Zoological Survey of India and Wetland Division, Ministry of Environment, Forest and Climate Change, Government of India).

Aquatic grasses providing food for waterbirds

Renuka Wetland is a vital habitat for terrestrial and aquatic organisms and the winter home of a wide range of migratory bird species. Aquatic grasses are a critical part of the lake ecosystem providing food and habitat for various aquatic animals and for birds. They also help keep the water clear and healthy by absorbing nutrients, trapping sediments, reducing erosion and adding oxygen. Hydrophytes within the Renuka wetland area include *Phragmites, Typha, Carex* and *Hydrilla.*

The phytoplankton, being the primary producers, constitute the basic food source of the lake, which supports fish and other aquatic animals and birds. As the lake is rich in nutrients, it supports a rich biological diversity. The green algae (Chlorophyceae) make up the majority followed by diatoms (Bacillariophyceae) and Myxophyceae. Spirogyra (Chlorophyceae) is dominant in winter. According to a faunal survey, the wetland has 443 species, from protozoans to mammals (ZSI, 2000).

2.2.3 Keystone and Ramsar-important species

There are 19 species of fish found in the Renuka (ZSI, 2000). The lake supports large numbers of Mahseer and indigenous species of lacustrine and stream fish (Baam *(Mastacambelus armatus),* Borna Snakehead *(Channa amphibius),* Chikli *(Nemacheilus sikmaiensis),* Khavali *(Puntius amphibius),* Rohu *(Labea rohita),* Saslu *(Rasbora caverii)* and Barred Baril *(Barilius barila)).*

Golden Mahseer

Golden Mahseer *(Tor putitora)* is listed as Endangered on the IUCN Red List. The species has suffered severe population decline in much of its distribution range and is now considered endangered. Once found across the Indian Himalayan biodiversity hotspot, the Mahseer has suffered significant depletion of its populations in recent decades due to multiple human stressors, compounded by climate change.

The Mahseer is a sensitive species that cannot tolerate a significantly modified water environment. The species prefers cold waters that have rich substrate composition. The species is migratory, moving upstream during rains. It prefers clean, fast-flowing and well-oxygenated waters and has a much lower fecundity rate (lays fewer eggs per kilogram of body weight) than most carps. It requires gravel/sandy stream beds to breed in and can migrate considerable distances in search of suitable breeding grounds. April to September is normally the spawning period, but younger fish are known to spawn earlier. Mahseer are omnivorous. They have voracious appetites, and their diet includes a wide range of algae, crustaceans, insects, frogs, other fish as well as fruits that fall from trees. Apart from having cultural and religious significance (Mahseer are protected in ‘temple sanctuaries’ across India), the Mahseer is an indicator of a healthy riverine environment.

The Golden Mahseer is very well protected in Renuka Wetland as no fishing is allowed for religious reasons. Yet, other factors threaten its habitat. Eutrophication is high, leading to less healthy space for fishes and reducing the availability of natural food and other key elements in the natural habitat. The Golden Mahseer’s breeding areas and activities are affected by the increasing silt load and surface temperature in shallow waters. The feeding of the fishes by religious visitors is another concern. The increase in artificial feeding was reported to be impacting the health of the fish and the water quality of the lake.

Turtles

The freshwater turtle species *(Batagur kachuga* and *Nilssonia hurum)* are found in the deep waters of Renuka Wetland. They have terrestrial nesting sites, however with increased and more intense rainfall, soil erosion is increasing, leading to silt deposition and subsequently eutrophication and loss of their habitat.

Suitable hydrological conditions are important for turtle survival. The deep water provides mating habitats for the turtles as well as cover, and the shallow stretches of the lake are used for foraging. The dry silt and sandy banks provide nesting sites. Freshwater turtle behaviour patterns include feeding and basking on exposed logs, rocks and sand banks. Those activities are influenced by changes in temperature. Their diet includes aquatic and terrestrial plants, invertebrates such as snails,

slugs, earthworms, crayfish and insects and even vertebrates like fish – all part of the lake ecosystem which will be affected by changing conditions. Freshwater turtles help control aquatic vegetation, serve as scavengers and help maintain the lake in a healthy condition. The Renuka Lake turtles are considered sacred and enjoy immunity from poaching.

Information on the three possible turtle species in Renuka Wetland from the IUCN Red List (https://www.iucnredlist.org/species/10949/ and /39618 and /39619)

Batagur kachuga inhabits large, swift-flowing rivers with sandy bottoms. This species is now only known with certainty from the Chambal River National Sanctuary, with 50 nests over 100 km. Basks on sandbanks, rocks and tree snags. Recorded food items are leafy vegetables, fruits and other plant material. Females reach 56 cm carapace length, males no more than 29 cm. Time to maturity about 18 years, based on captive-raised animals at the Lucknow Gharial Center, generation time well over 25 years. Females produce a single clutch of 11-30 eggs per year.

Nilssonia gangetica inhabits mostly rivers, and large canals, preferably with turbid water, muddy bottom and some current. Elevations up to 1,000 m. Lakes, oxbows, ponds and temporary waterbodies are used occasionally. It basks on riverine sandbanks and feeds on a variety of items, including animal matter (actively predating birds, reptiles, fish and invertebrates as well as eating carrion) and aquatic plants. It reaches a very large size; the largest animal recorded was 94 cm carapace length. Clutch size ranges from 8–35 eggs, and females produce several clutches annually. Age of maturity is approximately eight to nine years; a suggested generation length of 25–27 years; no longevity data is available.

Nilssonia hurum inhabits rivers, lakes and ponds. Lowland species up to 200 m elevation. It feeds omnivorously; reported diet items include snails and other molluscs, prawns, fish, and mosquito larvae; items fed in temple ponds include rice and sweetmeats. It reaches a size of about 60 cm carapace length and 15–20 kg weight. The age of maturity is perhaps seven to eight years, with a generation length of 20–25 years. There is no information on longevity.

Box 1 *Information on the three possible turtle species in Renuka Wetland*

2.2.4 Wetland ecosystems services

Recreation, tourism, religious tourism

Renuka Wetland is a unique wetland that attracts recreational as well as religious tourism. It is considered holy, and the Renuka temple is a popular religious pilgrimage destination situated near the lake. The calmness of the lake's scenic beauty also attracts tourists throughout the year. Boating and the mini zoo are popular recreational options for tourists. The tourists visit the wetland during summer as well as winter. It is the site of a religious fair held each year over the first two weeks of November.

There is one government hotel and one guest house located near the lake. Otherwise, there is little infrastructure available for tourist accommodation. Many ashrams dotting the banks of Renuka Wetland offer accommodation, but they operate according to their own distinctive rules, and if guests have not come for religious reasons the stay may not be pleasurable.

The historic religious fair is celebrated annually by lakhs (tens of thousands) of devotees from across the country coming to take a holy dip in the sacred Renuka Wetland. It marks the reunion of Lord Parshuram with his mother, Goddess Renuka, once a year. But the infrastructure to accommodate such a huge gathering of tourists is missing, and that puts a significant burden on the resources at the sensitive site.

Overall tourism is making a substantial contribution to the generation of employment and earning for locals.

2.3 Stakeholder roles and perceptions

Stakeholders and groups involved with the use or management of the Ramsar Site, and its natural resources are shown in Table 4, including official organisations, private sector, user groups and communities. Table 5 shows stakeholders' perceptions of the existing climate regime and recent extreme events at Renuka Wetland.

Table 4 *Stakeholder analysis of the Renuka Lake Ramsar site*

Stakeholder or group	Rights, roles and responsibilities of the Ramsar wetland site
District administration Sirmaur	Organising international Sri Renukaji fair in the wetland area
State Council for Science, Technology and Environment	Ministry of Environment and Forests, Government of India has designated the State Council for Science, Technology and Environment as a co-ordinating agency for the conservation and management of Renuka Wetland
Forest Department	The lake and its catchment area are a wildlife sanctuary. Divisional Forest Officer, Wildlife, Shimla is the custodian of the wetland and its catchment as the entire area is under the Forest Department, Government of Himachal Pradesh.
State Wetland Authority	The Himachal Pradesh State Wetland Authority (HPSWA), constituted in the year 2017 under the aegis of H.P. Council for Science, Technology & Environment (HIMCOSTE), is acting as a nodal agency for co-ordinating the Wetland Conservation Programme in the state with the active participation of all the stakeholders.
Renuka Vikas Board	The Renuka Vikas Board is a body constituted under the chairmanship of the local Deputy Commissioner to organise the international fair and oversee the temple operations and basic maintenance and beautification.
Zoo	The Renukaji Zoo is managed by Shimla Wildlife Division, which directly comes under the Himachal Pradesh State Government. The zoo is under the charge of the Ranukaji Range Forest Wildlife Officer.
Communities using the wetland	The local people are dependent for their livelihoods on the wetland through religious and recreational tourism-related activities, providing fish feed in the form of wheat flour dough, operating souvenir shops and selling items used as offerings in the temple, and snack shops.
Ashrams	Three ashrams provide free board and lodging to pilgrims.
Tourism Department	The Himachal Pradesh Tourism Department is managing a hotel in the area.

Table 5 *Stakeholders' perceptions*

Stakeholder or group	Perceptions of existing climate regime and recent extreme events, and concerns about climate change
Forest Department (Shimla)	No visible impact of climate change on the wetland at this stage although it is not thoroughly monitored. Mostly, the immediate impacts of human uses are the major factor in conservation of wetlands.
Wetland Authority	The impact of climate change is mostly indeterminate, but siltation and eutrophication are increasing, and unsustainable populations of fishes in the lake are fed mostly by visitors.

Stakeholder or group	Perceptions of existing climate regime and recent extreme events, and concerns about climate change
Renuka Vikas Board	The authority has not observed much impact of climate change on the lake at this stage, but human interventions have a major impact.
Forest Department Renuka Lake	Although the temperature has increased over the years, the Department has not observed any impact that can be directly linked to climate change. Siltation is rising due to construction of roads and forest degradation in the catchment. Also, the lake bottom has stagnant water and is suffering from eutrophication. There is an increase in the number of some specific invasive exotic plants around such as *Lantana* and an increase in the number of migratory birds.
HP Tourism Hotel	The Tourism Authority does not have any knowledge about the impact of climate change, but there is an increase in tourism, which brings with it added pressures on the lake.
Boatmen	The siltation is increasing, which may be attributed to an increase in extreme events such as high-intensity rainfall, but this is not supported by monitoring or data evidence.
DFO Renuka Lake	No particular impact of climate change has been observed. To some extent, the lake is a self-sustained micro-climate. There has been a change in the rainfall pattern and in the intensity of rainfall events, which may have some impact, but the overall annual precipitation is almost the same. The catchment has one of the best oak forests in Himachal Pradesh.

2.4 Current threats and trends

Renuka Wetland is a Ramsar Site and a wildlife sanctuary, distinguishing it from many other wetlands in India. The dependence of the population residing there is also very distinctive. After the declaration of the sanctuary, the wetland has undergone several changes. With the development in and around the lake taking place, locals were forbidden to extract services from the sanctuary which was once their forest. For ecosystem services such as fodder and fuelwood, some of the villages within the catchment area are still completely or partially dependent on the sanctuary.

The LULC maps of 1900, 2008 and 2018 (Figure 5) show that the areas of water bodies, which comprise the Renuka Wetland and the nearby Giri river, show little variation, but in recent decades, the area covered by these water bodies has significantly decreased. The area of the water bodies in 1990 was 0.20 km^2 (i.e., 1.25%, which decreased to 1.23% in 2008 and 1.06% in 2018). This can be attributed to the reduction in the nearby River Giri catchment after several dams were constructed in the upper reaches of the river in Himachal Pradesh.

Forest cover shows greater variations in these three periods i.e., 1990, 2008, and 2018. In 1990, forest cover was 12.85 km^2, i.e., 80.13% of the area, but in 2008 it decreased to 72% and then to 70% in 2018. The second most extensive land cover category is barren land, which has increased significantly over the 28 years to 2018 – around 2.32 km^2 (14.5%) in 1990, 3.34 km2 (20.82%) in 2008 and 3.84 km^2 (24.04%) in 2018 (Figure 5 and Table 6).

Increasing impacts of erosion, sedimentation and flash flood events have increased concern about the health of Renuka Wetland. The lake is shrinking. The increasing sediment load is worrying local communities and the administration.

The main threats to the lake environment identified by stakeholders during the baseline assessment are:

- Soil erosion and siltation
- Destruction and degradation of the catchment
- Fish feeding
- Garbage and littering
- Non-biodegradable materials dumped into the wetland by tourists and pilgrims
- The visitation during the religious fair
- Unregulated recreation and tourism
- Species invasion including alien species
- Pollution
- Lack of co-ordination between stakeholders and line departments
- Encroachment and land reclamation
- Over-harvesting of resources
- Climate change
- Weeds and eutrophication
- Poor law enforcement

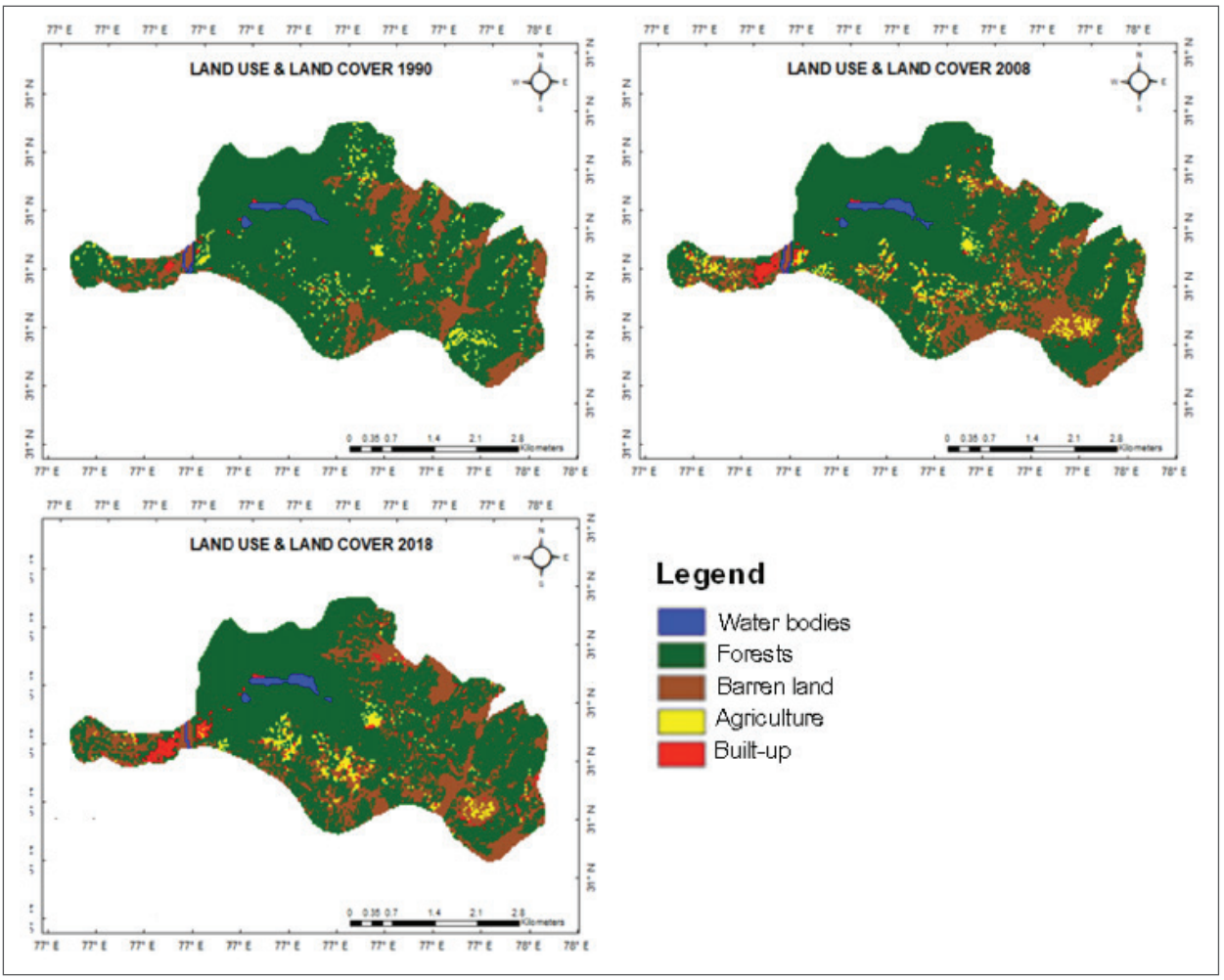

Figure 5 *Changes in land use and land cover between 1990 and 2018 in Renuka Tehsil (Source: Akash Gaur, 2020)*

Table 6 *Land use changes in Renuka Tehsil between 1990 and 2018*

Class	1990		2008		2018	
	(km²)	%	(km²)	%	(km²)	%
Water bodies	0.2	1.25	0.20	1.23	0.17	1.06
Forest cover	12.85	80.25	11.55	72	11.23	70
Barren land	2.32	14.5	3.34	20.97	3.84	24.04

Class	1990		2008		2018	
	(km^2)	%	(km^2)	%	(km^2)	%
Agricultural land	0.55	3.4	0.74	4.6	0.49	3.0
Urban – high density	0.10	0.6	0.20	1.2	0.31	1.9
Total area	**16.04**	**100**	**16.04**	**100**	**16.04**	**100**

Some important threats and trends were observed during the field missions to the Ramsar Site, which involved detailed interactions with the major stakeholders. It was observed that lake sedimentation and eutrophication are the biggest challenges and threats as shown by the clearly visible high sedimentation level on the banks. With climate change, the process of siltation and eutrophication may increase. The intensity of rain has increased over the years, and thus the threat of excessive erosion has increased. Another factor contributing to increased erosion and siltation in the catchment area is construction of infrastructure such as roads and settlements.

Due to the lack of any scientific data, the amount of silt coming into the lake each year is unknown. It was suggested that silt observation posts should be set up to monitor the yearly flow as well as the peak flow during the monsoon so that corrective conservation steps can be taken.

There is a de-notification process of certain areas from the wildlife sanctuary near the lake. The conservation stakeholders argue that de-notification will have negative impacts on the lake as well as surrounding catchment areas as the commercial and economic activities near the site will increase. Already, they are straining the lake ecosystem.

The area under the ashrams around the lake is increasing over time. The general perception of all the conservation authorities (Wildlife and Forest departments) is that concrete structures have been built and the site is under a threat from unabated encroachment.

Another concern is the leaching of waste material from septic tanks constructed around by ashrams, hotels and other commercial buildings. Expert opinion is that wastewater is leached into the lake, with subsequent impact on the quality of water and long-term health risks.

Although it is a Ramsar Site, bird censuses have not been carried out. The only reliable biodiversity data available are from the fauna survey conducted in 2000 by the Zoological Survey of India. These data are 20 years old, and there is no recent authentic up-to-date database of the migratory birds visiting the site.

The authorities are of the view that the religious fair that takes place every year has negative impacts on the lake. Officially the fair lasts for around a week, but unofficially it lasts for a month, and its impact on the lake and the surrounding areas lasts for much of the year, with some effects permanent.

There are no data available about the number of tourists visiting the site during the year as well as during the fair. This is a challenge in that no proper management plan can be made without concrete data.

The water sampling is not done regularly, and few agencies or institutes have conducted sampling in special studies. No yearly sampling data are available, and so monitoring of water quality is a significant issue.

There is no system for garbage disposal. Informal waste disposal has impacted the lake and surrounded areas.

Visitors feed the fish with unnatural foods, and this has led to health concerns regarding the fish. Since fishing is not allowed for religious reasons, there has been an unsustainable growth in the fish populations, which is likely to have impact on the lake water quality.

The other major problem is the funding cycle. The yearly departmental funds for the management activities of the lake remain mostly underutilised as funds are made available when the season for such activities has gone and the next allocation arrives again when such activities cannot be undertaken.

2.5 Current management arrangements and plans

2.5.1.1 Organisations responsible for the management of the site

The Government of Himachal Pradesh has constituted a State Steering Committee under the chairmanship of the Chief Secretary Government of Himachal Pradesh for examining the Action Plan and reviewing the implementation progress over time. The Steering Committee approves the annual action plan for conservation and management of all the Ramsar wetlands in Himachal Pradesh, including the Renuka wetland.

At the local level, all activities are monitored by the DFO Wildlife Shimla in consultation with the Chief Conservator of Forest Wildlife and Principal Chief Conservator of Forest Wildlife HP, who also undertakes tours to physically check the works.

2.5.1.2 Current management measures

The management plan is designed to address the threats to the wetland and to engage identified stakeholders in the process to ensure better utilisation of resources as well as inculcate a sense of shared responsibility towards the conservation of the Renuka wetland, particularly among those agencies that are operating in the area to earn revenue. The management objectives are:

- **Habitat improvement**
  - Plantation of degraded areas with native broad-leaved species of fodder value to phase out old plantations of non-native species
  - Gradual eradication of weeds like *Lantana* and *Adhatoda vasica.*
  - Carrying out soil stabilisation works in the erosion-prone areas by constructing engineering structures along with vegetative spurs to reduce the silt entering Renuka Wetland and to improve the general habitats of the wetland.
  - Improving the aquatic ecosystem of the lake
  - Provide nesting sites for the Red-Crowned Roof Turtle *(Batagur kachuga)* and Indian Soft-Shelled Turtle *(Nilssonia gangetica)*
- **Tourism management**
  - Regulation of movement of tourists in the temples around the lake
  - Providing basic amenities to tourists. Developing facilities such as benches and rain shelters around the parikrama road, and toilets at appropriate distances, for the benefit of the tourists.
- **Education and interpretation**
  - Engendering awareness in people about the need to conserve the wetland by laying out nature and educational trails and establishing an information and interpretation centre
  - Placing directional signage, interpretation signage, educational signage, 'do's & don'ts'
- **Religious tourism [mela] management**
  - During the annual fair, organised in the fairground, tens of thousands of people visit the area. Special arrangements are made for the movement and stay of the people.
  - Certain core areas should be cordoned off during this time.
  - Special arrangements are to be made for the disposal of garbage and sanitation facilities.
  - On-site treatment of wastewater should be incorporated in the fair management to ensure that the large numbers of visitors cause minimal pollution.
  - Post-fair cleaning of the ghats needs to be taken up.
- **Eco-development**

Soliciting the involvement of people in conserving and improving the ecology of the area by carrying out eco-development works in the surrounding villages.

- **Protection of wetland**

Reducing the incidence of illicit lopping and grazing by effectively fencing the area around the wetland and by patrolling (by the staff)

- **Monitoring and research**

- Carrying out an annual wildlife census
- Scientific study on the wildlife in this area and its habitat and possible connectivity corridors with the larger landscape
- Carry out research on the Red-Crowned Roof Turtle *(Batagur kachuga)* and Indian Soft-Shelled turtle *(Nilssonia gangetica)*
- Monitoring water quality
- Monitoring silt load

The management plan provides an appropriate and comprehensive set of activities that need to be conducted for the sustainability and rehabilitation of the Ramsar Site. If effectively implemented, the measures will also be important components of a climate change adaptation plan for the site. It is evident that there are gaps in the effective implementation of the management plan and that the wetland is steadily degrading – potentially irreversibly. It is also evident that the current institutional arrangements of the site management are complex and tend to hamper rather than facilitate systematic management actions.

3 CLIMATE CHANGE AT RENUKA LAKE

3.1 Current and past climate

Renuka Wetland is located in Sirmaur district, Himachal Pradesh. It lies in the Inner Himalaya geo-climate zone, which is one of the three geo-climate zones of Himachal Pradesh (along with the Outer Himalaya and Alpine zones). The climate of the Renuka Wetland area is sub-tropical to temperate, depending on the elevation. Winter extends from late December to February and the pre-monsoon season from March to May, followed by the monsoon period, which extends from June to September, and the post-monsoon, from October to December.

3.1.1 Precipitation

Sirmaur district receives a medium-high rainfall (with average rainfall from 1210 mm to 1500 mm per year), compared with other areas in the Himachal Pradesh region (Figure 6). The rainy season usually begins in the middle of June and lasts till the middle of September, with a seasonal average of 1160.1 mm. As shown in Figure 7, the rains are more active during July and August, and about 80% of the rainfall is received during these months, with mean rainfall values of 415.2 mm and 383.8 mm, respectively. A shower or two are received in April and May, which may bring hailstorms.

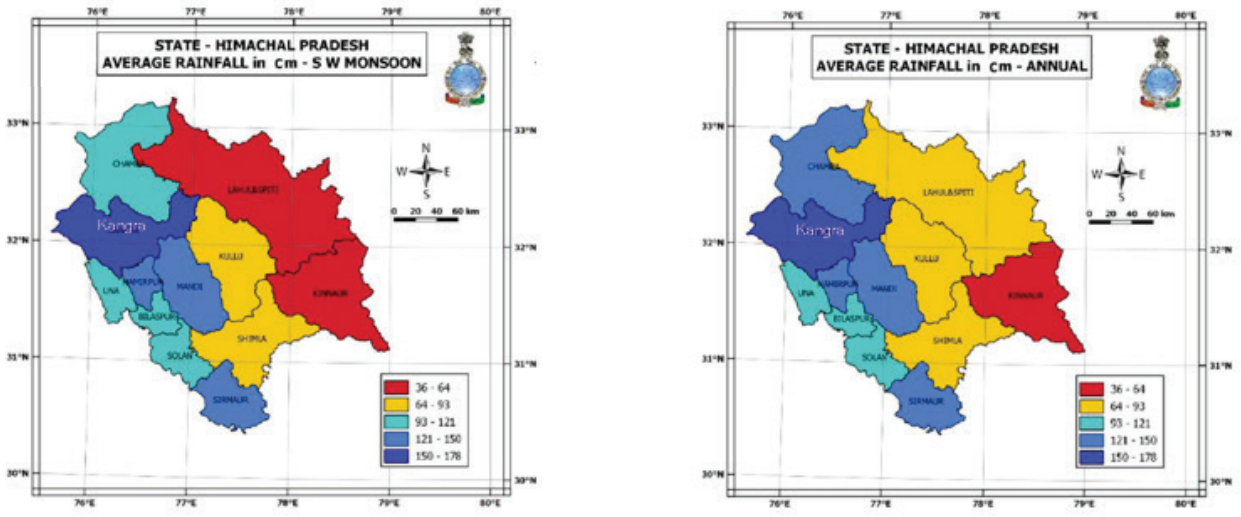

Figure 6 *Mean rainfall patterns of Himachal Pradesh. Renuka Lake is located in Sirmaur district (red box). (Source: IMD, 2020)*[4]

[4] Observed Rainfall Variability and Changes Over Himachal Pradesh State. Issue No. ESSO/IMD/HS/Rainfall Variability/10(2020)/343. Issue Date" January 2020

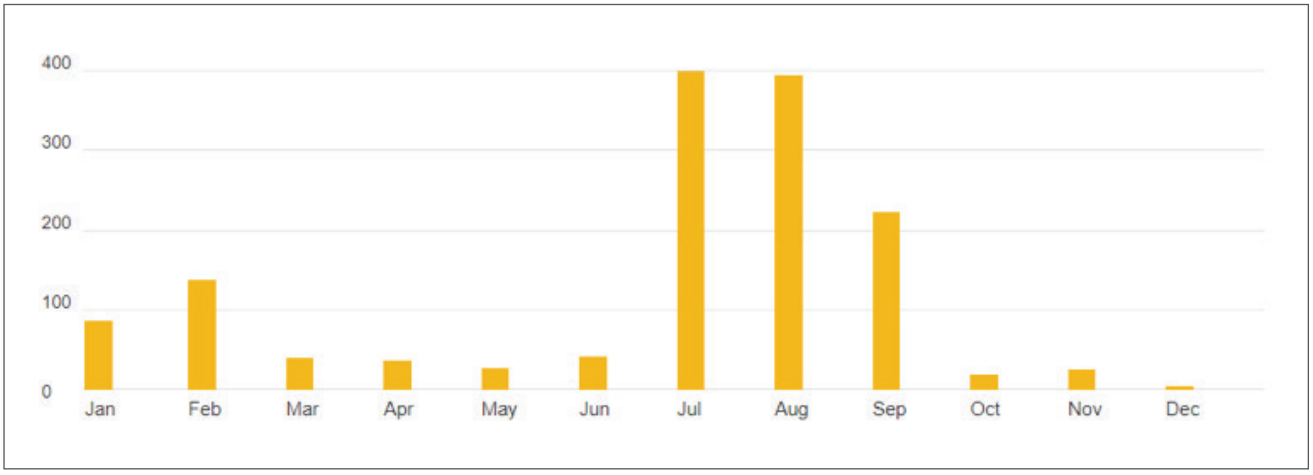

Figure 7 *Mean monthly rainfall in Renuka Wetland*
(Source: Department of Environment, Science & Technology)

Since 1979, the precipitation has changed across the Sirmaur district although there is no consistent pattern (IMD, 2020). Changes in the rainfall vary, with increases in some areas and decreases in others. The changing and more unpredictable precipitation patterns may have serious consequences for the region, including flash floods in the north and increased droughts in the southern plains.

The annual average frequency of rainy days in the Renuka Wetland area ranges from 63 to 62 days, and during the monsoon the frequency is 33.9 to 42 days. Importantly, over the last three decades, the frequency of rainy days in this area has significantly reduced.

3.1.2 Temperature and wind

The cold season in the Renuka Wetland area is from December to February, with the lowest temperature being about 11°C (Figure 8). The hot season which follows lasts until May, with the highest temperature up to 30°C. In the cold, summer and post-monsoon seasons, the air is dry, particularly in the afternoon, while the air is humid during the monsoon. The skies are generally clear or lightly clouded except during the monsoon, when they are heavily clouded to overcast.

The winds are light to moderate, but during the monsoon, they become stronger. During the monsoon, the winds are from the South-West to the North-West, the westerly being more frequent. In the post-monsoon season, they are predominantly from the North-East or East. Easterlies and southeasterlies are common in the cold season.

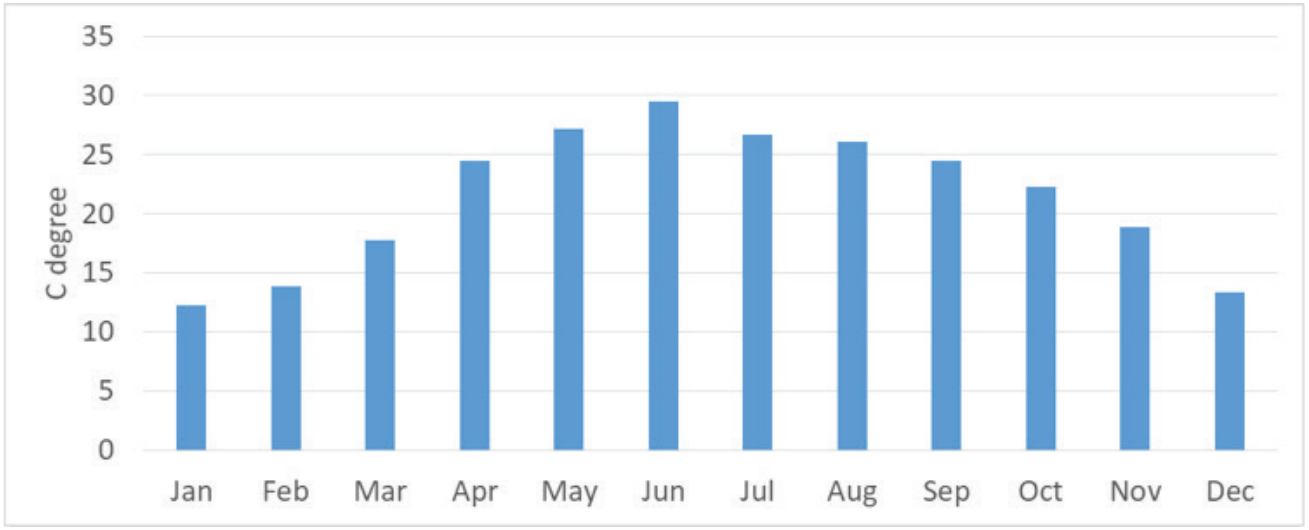

Figure 8 *Average monthly temperature at Renuka Wetland*
(Source: Department of Environment, Science & Technology)

3.2 Bioclimate zones

The bioclimate zones around Renuka Wetland are shown in Figure 9. The immediate area around Renuka Wetland is classified as Hot and Mesic (moderate moisture), and this area generally follows the Giri river valley. The area around the valley is classified as Hot and Dry. With the overall projected increase in annual rainfall, despite decreases in the dry season, it is not expected that the bioclimate in the immediate area around Renuka Wetland will change significantly, i.e., it will remain Hot and Mesic. On the other hand, the situation in the overall Renuka Wetland catchment is anticipated to change significantly, affecting the downstream ecosystems.

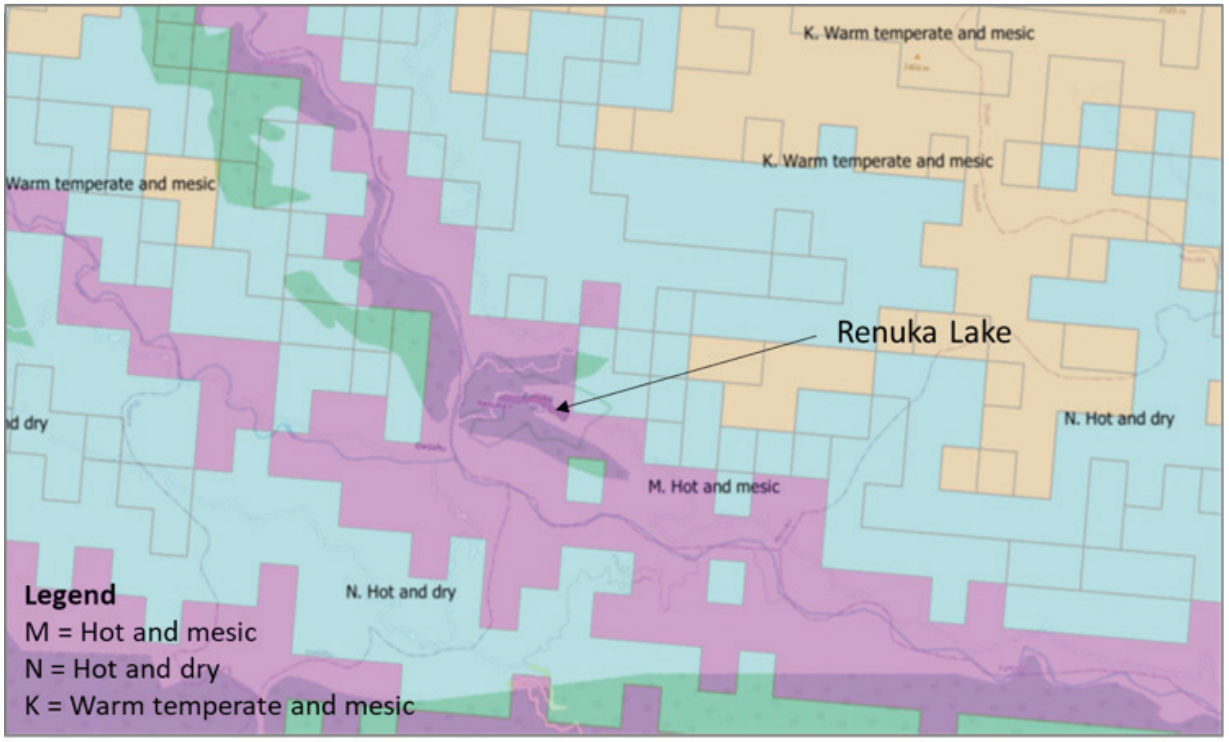

Figure 9 *Bioclimate zones around Renuka Wetland (Source: Adapted from GEnS_v3)*

3.3 Climate change projections

This section presents projections of the precipitation and temperature at Renuka Wetland by the 2050s, with respect to the baseline period of 1960 – 1990. These results were generated using an ensemble mean of three selected GCMs (CCSM4, HadGEM2-ES and MIROC-ESM) with the RCP 8.5 scenario.

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 Renuka Wetland are shown in Table 7 and Figures 10-13. Overall, the total precipitation is projected to increase during the SW monsoon, while it will decrease during the other seasons.

The total precipitation is projected to significantly increase by 224.9 mm (12.6%) during the SW monsoon (June – September), from 1789.5 mm to 2014.4 mm by the 2050s. In contrast, the total precipitation is projected to decrease during the NE monsoon (decreasing by 12.3 mm or 9.2%), in winter (decreasing by 11.3 mm or 7.9%) and in summer (decreasing by 7.1 mm or 6.0%).

Higher rainfall during the SW monsoon and lower rainfall during the dry season are projected to happen in the immediate

upstream zones of Renuka Wetland (Figures 10-13). Higher rainfall during the rainy season may threaten the Ramsar site with a higher risk of flash flooding and riverine floods. The higher rainfall in combination with the change of temperature will increase the turbidity in the lake, which may impact fish and aquatic ecosystems. Higher rainfall, extreme floods and storms could impact surrounding terrestrial ecosystems. Lower rainfall in the dry season may cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar Site.

Table 7 *Projections of seasonal precipitation change by the 2050s at the Renuka Lake Ramsar site*

Season	Baseline 1960–1990 (mm)	Projection 2050s (mm)	Change (mm)	Change (%)
Winter (Jan – Feb)	143.8	132.5	-11.3	-7.9
Summer (Mar – May)	119.0	111.9	-7.1	-6.0
SW monsoon (Jun – Sep)	1789.5	2014.4	224.9	12.6
NE monsoon (Oct – Dec)	133.5	121.2	-12.3	-9.2

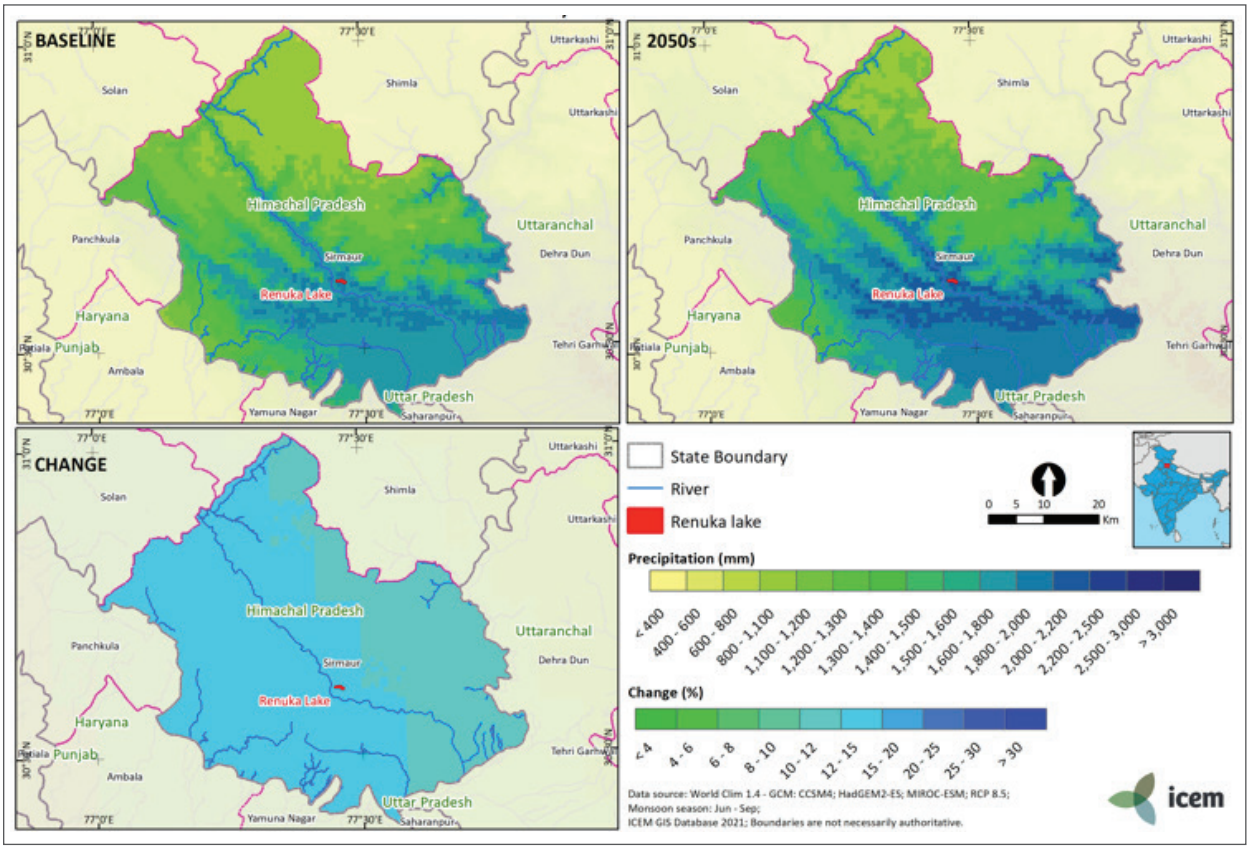

Figure 10 *Projections of precipitation change during the SW monsoon (June - September) in Sirmaur district*

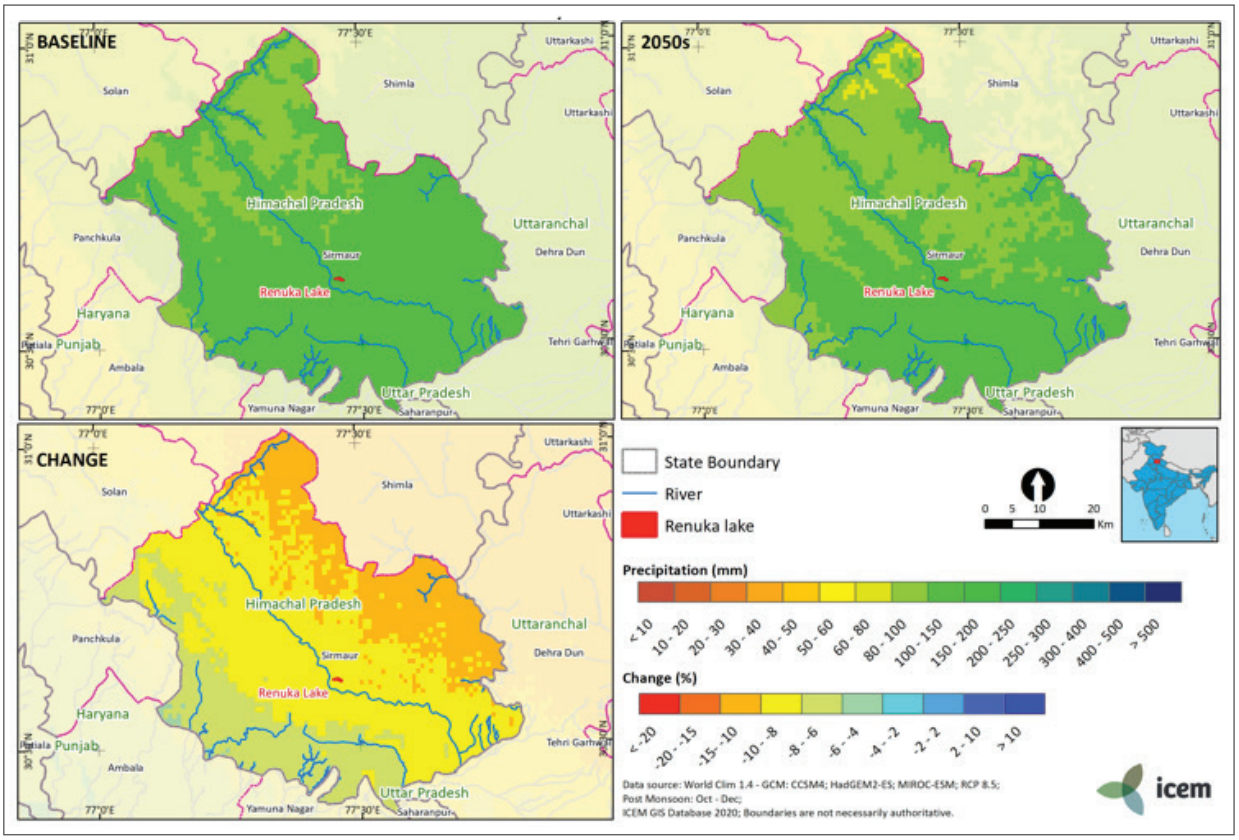

Figure 11 *Projections of precipitation change during the NE monsoon (October - December) in Sirmaur district*

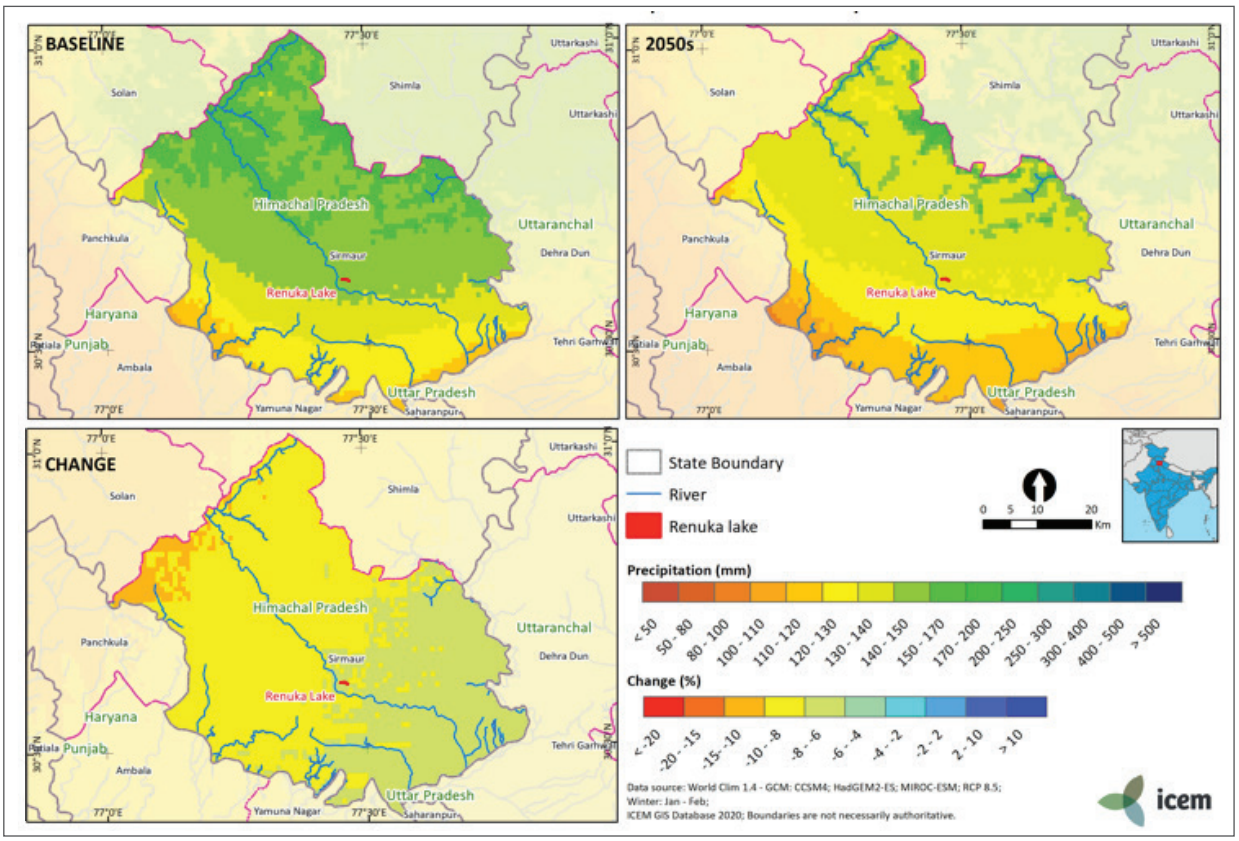

Figure 12 *Projections of precipitation change during winter (January - February) in Sirmaur district*

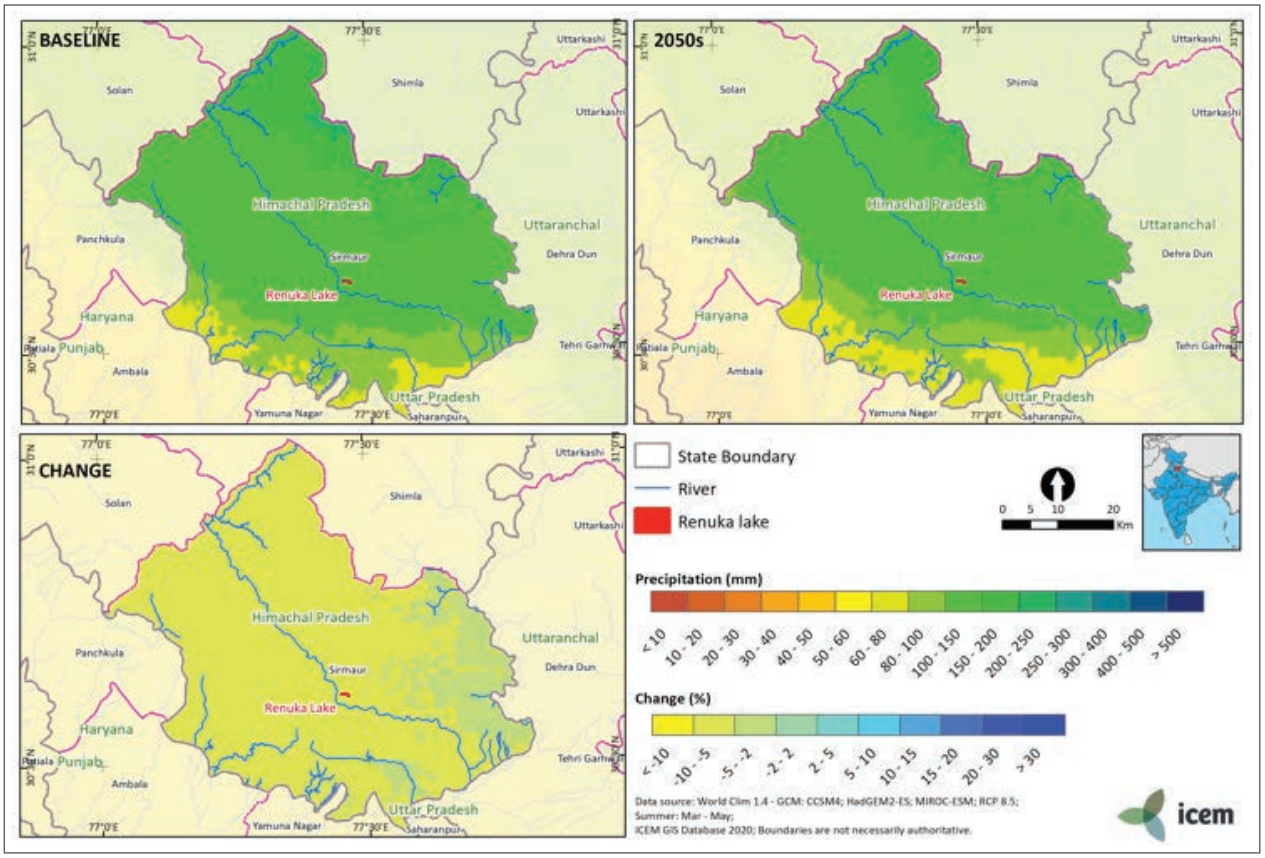

Figure 13 *Projections of precipitation change during summer (March - May) in Sirmaur district*

3.3.2 Projections of temperature

Projections of the average maximum temperature and its changes by the 2050s, with respect to the baseline period of 1960 – 1990, are shown in Table 8 and Figures 14-17. Overall, the temperature is projected to increase by 2.1°C to 3.3°C by the 2050s. These are very significant projected increases with major implications for the Ramsar ecosystems.

The most significant increase is projected for summer (March – May), with an increase of 3.3°C, from 30.9°C to 34.2°C. The least significant increase is projected for the SW monsoon (June – September), with an increase of 2.1°C, from 31.1°C to 33.2°C. Temperatures during both the NE monsoon (October – December) and winter (Jan – Feb) are projected to increase by 2.8°C (from 24.2°C to 27.0°C during the NE monsoon and from 19.2°C to 22.0°C in winter).

These changes are certain to lead to ecological stresses and shifts, including changes in species composition and populations, higher siltation and lower lake water levels.

Table 8 *Projections of seasonal temperature change by the 2050s at the Renuka Wetland*

Season	Baseline 1960 – 1990 (°C)	Projection 2050s (°C)	Change (°C)
Winter (Jan – Feb)	19.2	22.0	2.8
Summer (Mar – May)	30.9	34.2	3.3
SW monsoon (Jun – Sep)	31.1	33.2	2.1
NE monsoon (Oct – Dec)	24.2	27.0	2.8

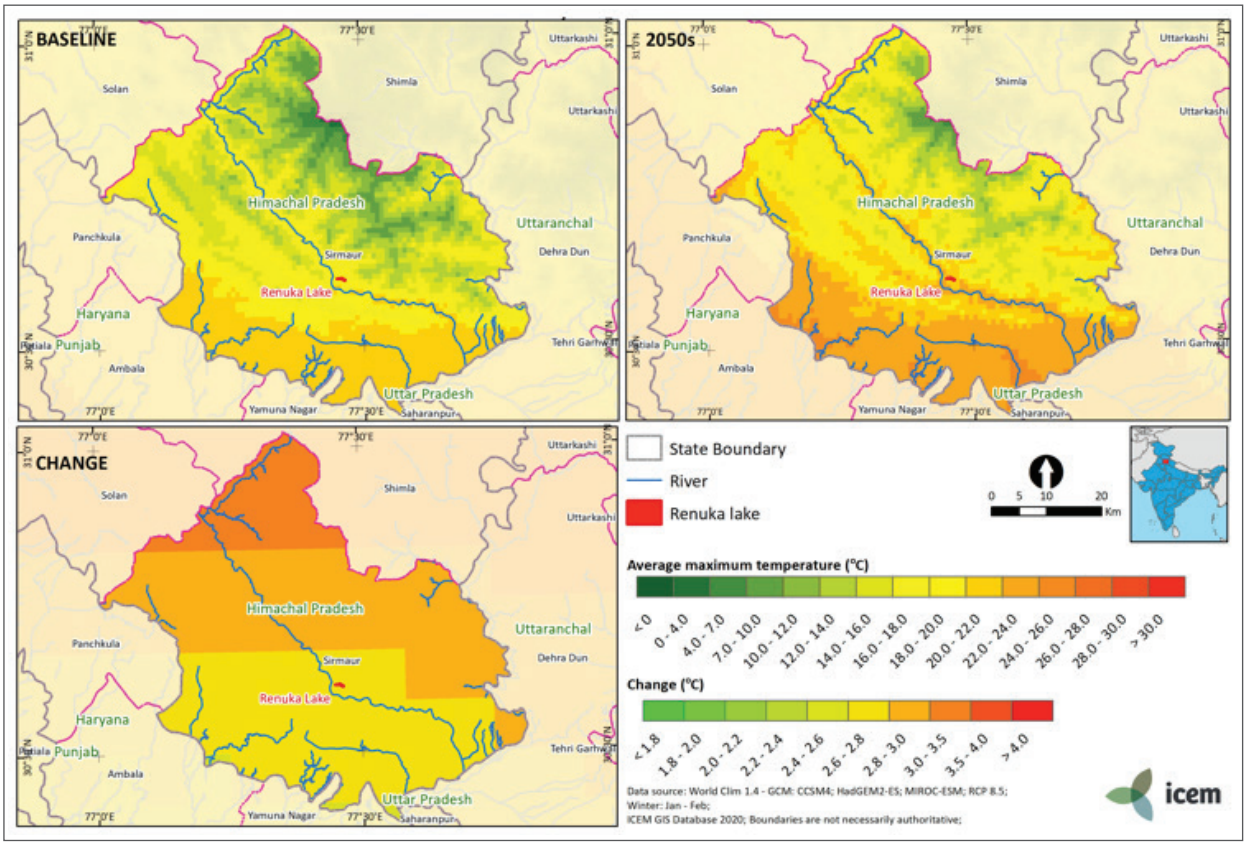

Figure 14 *Projections of change in temperature during winter (January - February) in Sirmaur district*

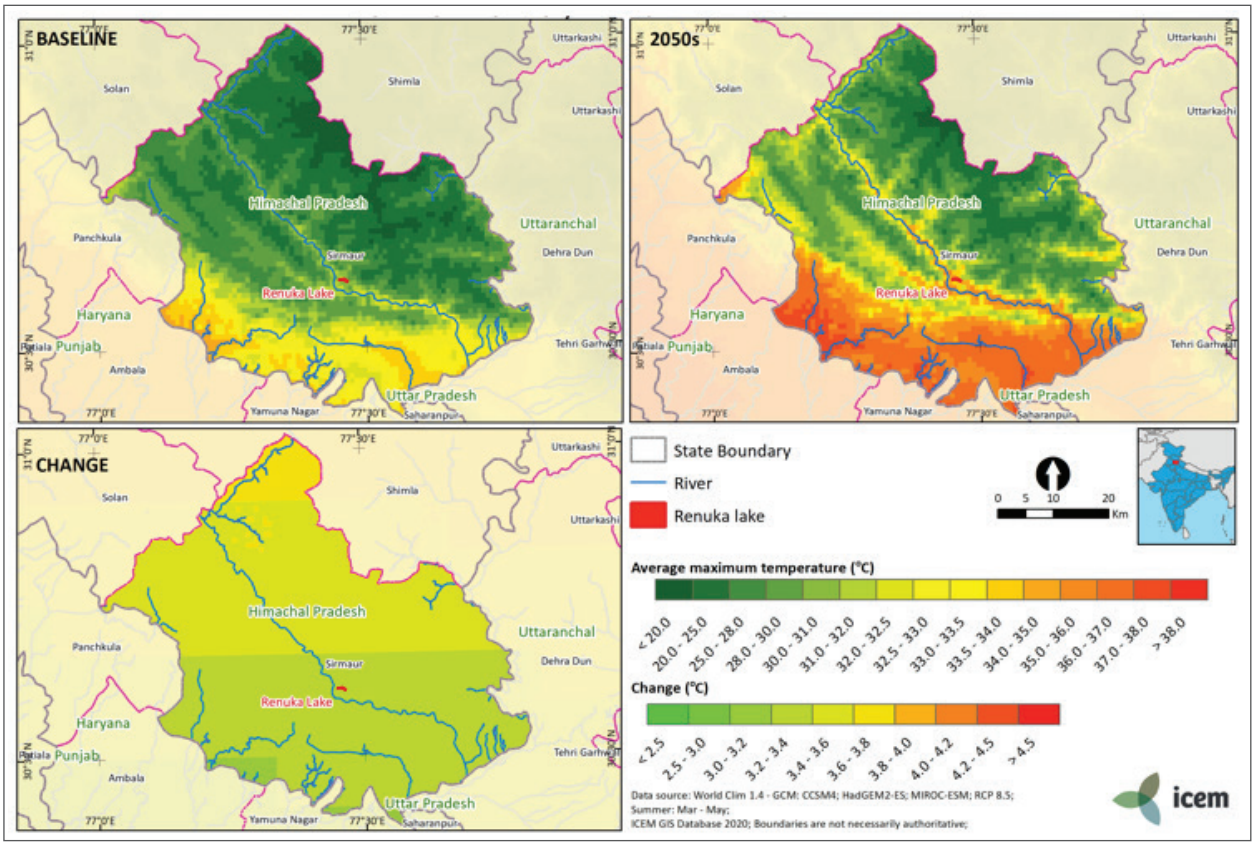

Figure 15 *Projections of temperature during summer (March - May) in Sirmaur district*

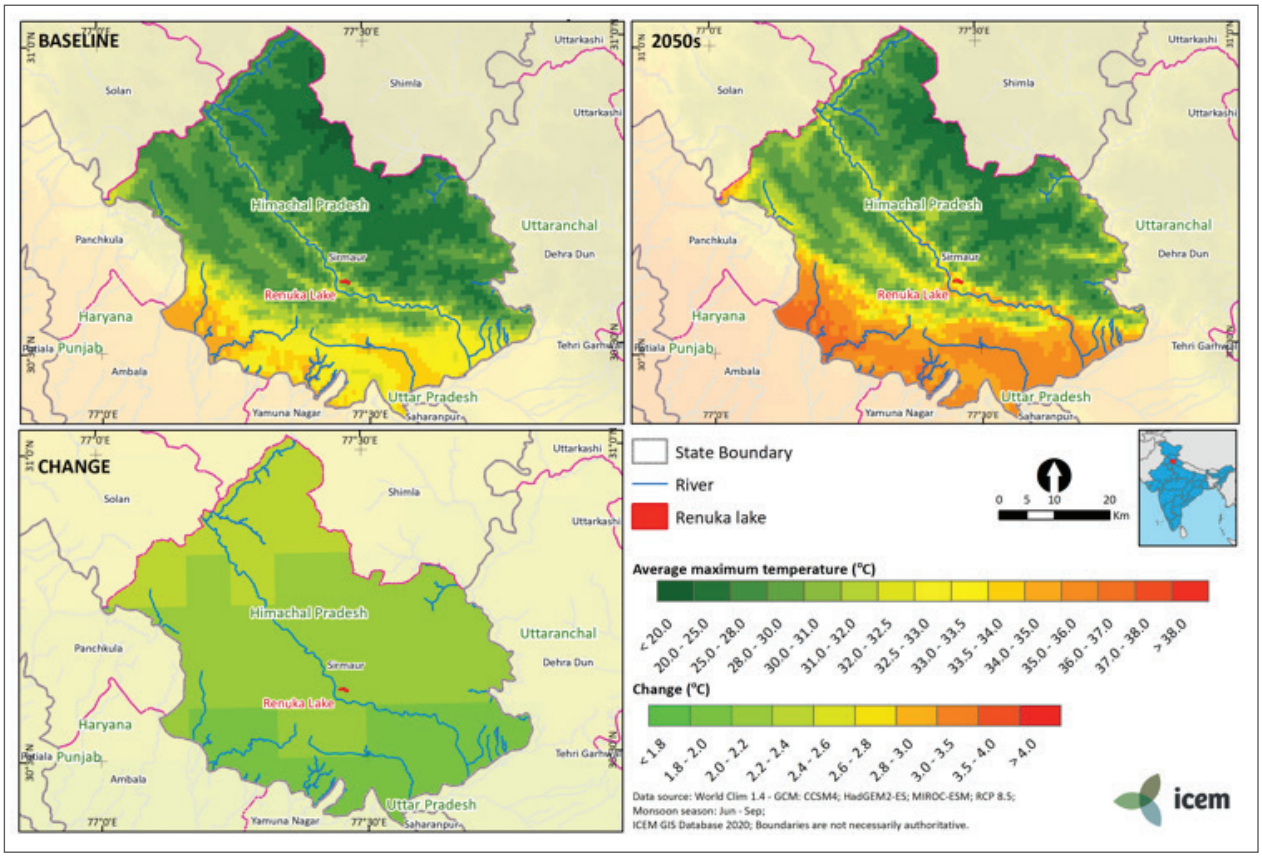

Figure 16 *Projections of temperature during SW Monsoon (June - September) in Sirmaur district*

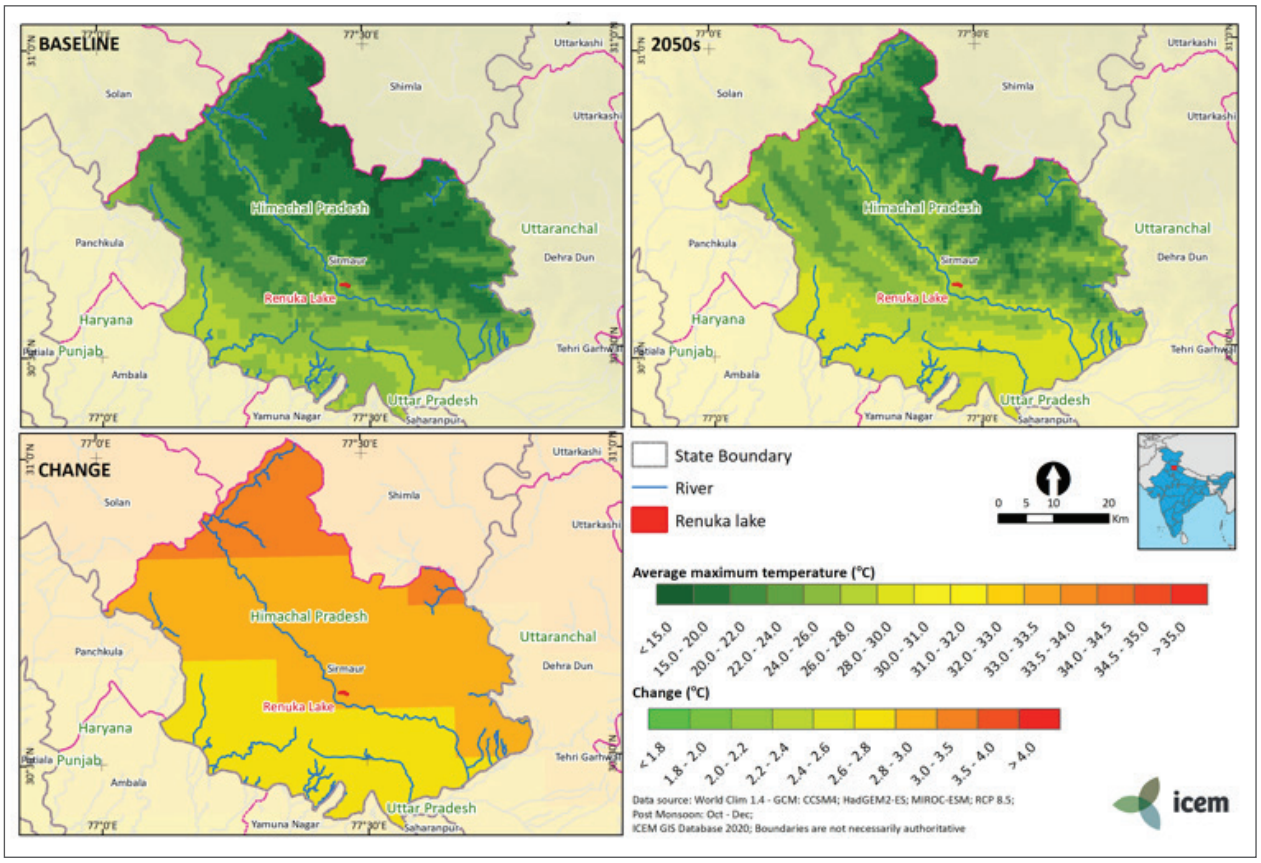

Figure 17 *Projections of temperature during NE Monsoon (October - December) in Sirmaur district*

3.3.3 Extreme events

Higher rainfall during the rainy season may threaten the Ramsar Site with a higher risk of flash flooding and riverine floods. The higher rainfall in combination with the change of temperature will lead to increasing the turbidity in the lake that may impact fish and aquatic ecosystems.

Higher rainfall, extreme floods and storms can impact surrounding terrestrial ecosystems. Lower rainfall in the dry season may cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar Site.
The higher temperature in the hot season may cause a higher risk of forest fires.

In summary, the projected climatic changes at Renuka Wetland and its catchment are very significant. They will have far-reaching effects on the lake and catchment ecosystems that need to be fully understood and managed if the site is to retain its biodiversity and cultural values. Those values are already under serious threat.

4 IMPACT AND VULNERABILITY ASSESSMENT

4.1 Vulnerability summary of the Renuka Wetland

The climate change vulnerability matrix (Figure 18 and Annex 2) indicates that climate change is already impacting Renuka wetland ecosystems, and that forest and water ecosystems are increasingly exposed to stress and shocks from direct and indirect impacts of rising temperatures and extreme rainfall events.

Changes in rainfall intensity and frequency of extreme events such as drought and flooding will continue to have negative effects on the Renuka Wetland. Changes in air temperature and precipitation have direct effects on the physical, chemical, and biological characteristics of a lake (Vincent, 2009). Climate change has the potential to change the physical structure of Renuka Lake ecosystems and lead to alteration of aquatic biota.

The increased rain intensity is leading to increased sedimentation in the lake due to erosion and runoff. Too much sediment deposition can bury habitats and impact benthic creatures. Silt and increased nutrient level are accelerating the lake's eutrophication, and the projected increase in temperature can facilitate algal blooms that produce harmful toxins and can kill aquatic life. Increased water temperature can affect fishes directly by affecting their physiology, growth and indirectly their behaviour, including spawning patterns. With the accelerated decrease in lake size and increase in the area of dry banks, the habitat of various aquatic creatures and migratory birds is under threat. The increased organic load may also impact the habitat of various aquatic species, endangering their long-term survival.

The projected changes are likely to impact the forests in the catchment resulting in changes in species composition and biodiversity. For example, Sal and Shisham, the two major forest species in the Renuka Wetland catchment, are considered vulnerable to climate change. Various studies conducted across Himalayan ranges have reported the impact of climate change on these tree species, decreasing their survival and regeneration. Climate-related extreme weather phenomena such as high temperatures will also increase evapotranspiration and impact soil moisture and biodiversity.

Ground water resources may be affected as high-intensity rains lead to runoff from the slopes with very little percolation in a degraded, partially deforested catchment. Ground water levels will tend to fall during droughts and prolonged dry seasons. Results and analyses of the detailed vulnerability assessment matrices for the target assets are presented in the sections to follow, considering the different climate threats. The detailed Vulnerability Assessment Matrix of each target asset is attached as complementary material to this report (Annex 2).

Threats	Catchment- Surrounding Hillsides					Habitats					Golden Mahseer					Bengal Roofed Turtle					Aquatic grasses					Recreation, 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–Sep)	H	H	H	VL	VH	H	H	H	VL	VH	H	H	H	M	H	VH	VH	VH	VL	VH	H	H	H	L	H	H	H	H	L	H
Decrease of rainfall during dry season (Oct-May)	M	M	M	VL	H	L	M	M	M	M	L	L	L	L	M	H	H	H	L	H	M	M	M	H	M	M	M	M	M	M
Temperature																														
Increase of temperature during Winter (Jan-Feb)	H	H	H	L	H											H	H	H	L	H	H	H	H	L	H	M	M	M	L	M
Increase of temperature during Summer (Mar-May)	H	VH	VH	L	VH	H	H	H	L	H	H	H	H	L	VH	L	L	L	L	M	H	H	H	L	H	L	L	L	H	L
Increase of temperature during Monsoon (Jun-Sept)	M	M	M	M	M	M	M	M	L	M	M	M	M	L	M	M	M	M	L	M	M	M	M	L	M	H	H	H	L	H
Increase of temperature during Post-Monsoon (Oct-Dec)	H	H	H	L	H	H	H	H	L	H	M	M	M	L	M	M	M	M	L	M	H	H	H	L	H	L	L	L	L	L
Extreme events																														
Flash Flooding	VH	VH	VH	VL	VH	H	H	H	VL	VH	H	H	H	L	H	VH	VH	VH	VL	VH	H	H	H	L	H	H	H	H	L	H
Drought	H	H	H	VL	VH	H	H	H	L	H	H	H	H	L	H	H	H	H	VL	VH	H	H	H	L	H	H	H	H	L	H
Fires	VH	VH	VH	VL	VH						H	H	H	L	H															

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

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

Figure 18 *Summary of vulnerability scores for Renuka Wetland*

4.2 Asset 1: Catchment

Summary description of the catchment asset

The catchment around Renuka Wetland possesses a rich biodiversity. The southern slopes are steep (50° to 55°), whereas the northern side is characterised by gentler slopes. The hills that surround the lake from its northern and southern sides are covered with dense subtropical dry deciduous forests. The eastern catchment area of the Lake has lower forest cover. Hydrologically the catchment of the wetland is drained by 21 small and big streamlets, which receive water mainly during the rainy season. The Lake receives most of the sediment from the catchment through streams and surface erosion. The steep slopes surrounding Renuka Wetland are a major erosion factor, leading to the high sedimentation rate. The Renuka Wetland catchment is fragile as these mountainous ranges are young and are more prone to erosion.

Exposure to the projected climate changes

High-intensity rainfall is already leading to runoff and erosion from the catchment hills, and climate change will have a negative impact on the catchment. With exposure to higher and increased-intensity rainfall projected during the monsoon, the catchment area will be more prone to soil erosion and landslides. The increased high silt load coming into the lake from the catchment in recent times is an indication of impacts from high-intensity rain.

Sensitivity to the exposure

The catchment area, with its seasonal streams is very sensitive to high-intensity rains and higher rainfall, especially during the monsoons, as these lead to increased erosion and high silt loads being brought down to the lake. In turn, this further degrades the catchment with low rainwater percolation, decreased ground water holding capacity and ground water recharge. Ground water and spring water output are directly related to a decrease in recharge. It will reduce the output of the springs feeding the Renuka Lake throughout the year, even if the rainfall in the wet season is increasing. Decreased rainfall in the dry season may lead to the drying of perennial streams and springs in the catchment. The decreased soil moisture and decreased fertility due to the loss of topsoils in the catchment will directly impact the vegetation cover of the catchment area. The increase in temperature will impact forests, increasing evapotranspiration, leading to dryness and increased forest loss.

Projected impacts of climate change on the catchment

With increased high-intensity rainfall during the monsoon, the catchment will be more prone to soil erosion. Increased rain intensity will lead to faster runoff from the catchment, which in turn will result in a decline of the water table and soil moisture as the runoff will not have sufficient time to recharge the ground water. The catchment's water-holding capacity will be reduced, resulting in less water reaching the aquifer and ultimately leading to less water in the lake.

A decrease in ground water recharge will directly have a bearing on the biodiversity as well as long, dry spells during the dry season (October - May) will lead to loss of soil moisture. Soil moisture plays a key role in determining the biodiversity of the area. On hill slopes, this becomes all the more important as the surface runoff is high, and loss of top-soils and low recharge will further degrade the catchment, leading to less forest cover and to habitat changes.

The increase in temperature during summer will impact the forests negatively. It will lead to dryness, increased incidences of heat stress, leading to increased mortality in trees during summer and dry seasons. The increase in temperature during summer will lead to increased vulnerability to fire incidents resulting in further tree mortality in the catchment.

Increasing high-intensity rainfall brings the challenge of flash floods degrading the catchment further. Runoff from the slopes in the catchment will carry silt, sand and gravel with organic content reducing the nutrient-rich topsoils of the catchment.

In the Renuka Wetland catchment, there is a natural Sal and Shisham forest, but both species are facing problems of mortality and low regeneration. According to the Renuka management plan, these problems may have some connection with the rise in temperature due to climate change – this requires further research. Across India, it has been reported that climate change is having an impact on Sal forests. For example, "Rising temperatures in the hill state have altered patterns of flowering and seed fall in Sal trees, which has hit their natural regeneration and led to a decline in their numbers in forests, according to a study led by IFS officer, Sanjiv Chaturvedi"[5]. Also, it has been reported that Shisham *(Dalbergia sissoo)* is declining sharply due to a mix of anthropogenic and climatic factors in the Himachal (DoEST, 2012; Aggarwa & Chauhan, 2015). The high rate of Shisham mortality in India was linked with changing climatic conditions, such as increased drought and extremes in winter and summer, with severe foggy conditions which affected the photosynthesis and other physiological processes of the trees negatively (Singh, 1980; Kaushal et al., 2002; Ahmad et al). These changes will lead to shifts in tree cover in the Renuka Wetland catchment.

The invasive alien species *Lantana camara* has already encroached on major parts of the catchment as described in the Renuka management plan. Climate change will create favourable conditions for this hardy invasive. *Lantana* can tolerate high temperatures and moisture levels with an ability to adapt to the changing climate: "The chances of invasiveness of *Lantana* are high in future due to its rapid spread, high adaptability to different environments, tenacious resistance to cutting and burning and climate change (Taylor et al., 2012; Zhang et al., 2014)" (Qureshi et al., 2021).

Adaptive capacity of the asset and management arrangements

Thus dryness, changes in biodiversity, increased mortality in forests due to heat stress and increased instances of forest fires, erosion and runoff caused by increases in temperature are the many ways in which climate change will impact the catchment. The evidence of reduced catchment quality and a very weak response to these impacts indicates that the overall natural adaptive capacity of the catchment is low. There is limited institutional and financial capacity to adapt and manage these impacts in the catchment area, which will remain highly vulnerable until various conservation measures are adopted.

4.3 Asset 2: Aquatic habitats

Renuka Wetland and its catchment provide the habitats for many wildlife species – terrestrial wild animals, aquatic life and many species of local and migratory birds. The aquatic habitat is shrinking. Over the past two decades, the depth and area of the lake has shrunk considerably (SANDRP, 2020).

[5] http://timesofindia.indiatimes.com/articleshow/64440389.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

Exposure

High exposure to warming from climate change is expected to alter habitats and amplify existing threats in various ways. Increasing air and water temperatures will modify the biodiversity, for example, by threatening existing breeding habitats of aquatic species, causing shifts in the biotic components of the freshwater ecosystem and leading to the dying out of some more sensitive species and their replacement by species better suited to the new conditions. Increasing incidents of floods are expected to increase erosion levels, reduce water quality, degrade and eliminate aquatic habitats, cause increased organic loads and eutrophication and open the way to invasions by non-native species. Climate changes on the projected scales will drive large-scale shifts in species distribution and abundance and reorganisation of terrestrial and aquatic ecosystems (Lenoir and Svenning, 2015; Pacifici et al., 2017; Staudinger et al., 2012).

Sensitivity

Given the existing pressures, the lake and its most important species and habitats from a Ramsar conservation perspective are very sensitive to the projected levels of change. Due to climate change, the lake habitat is shrinking at a faster rate. Many local and migratory birds are dependent on those habitats. As the area of the lake shrinks, food availability will decrease and competition for reduced resources will increase. Of course, if the lake continues to shrink at a faster rate, it will eventually affect all 443 species of animal that are associated with it.

In the future, altitudinal shifts in vegetation can be expected. The plant species that inhabit the mountains of Himachal have already started to migrate to higher altitudes due to warming (Padma 2014), and some are in danger of being lost before their existence has been recorded (Vindhya Prasad Tewari et al., 2017). In Himachal the projections also indicate a north-eastwards shift in biomes in the Himalaya as conditions become warmer and the tree line moves to higher altitudes (Prentice et al. 1992., Deshingkar et al., 1997). These wider regional shifts will be accompanied by micro-ecosystem shifts in and around Renuka Lake.

Impacts

During the monsoon, higher temperatures and nutrients from the catchment will increase the rate of eutrophication in the lake. The lake is relatively shallow with a depth varying from 1m to 13 m so readily affected by any changes in nutrient and sediment flows. Acceleration of eutrophication is a prime concern as the lake size is small, as is its carrying capacity. Eutrophication leads to increased incidences of algal blooms which limit light penetration. When these dense algal blooms eventually die, decomposition severely depletes dissolved oxygen, creating a hypoxic or anoxic ‘dead zone' lacking sufficient oxygen to support most organisms (Chislock et al., 2013). A major climate change concern at temperate latitudes is the prospect of a shift in the phytoplankton species composition toward dominance by species of cyanobacteria that form noxious blooms (Vincent, 2009). Also, the increase in temperature can alter the natural species balance of the lake as “increase in temperature can influence the length of the growing season with consequent increases in bacterial and phytoplankton productivity” (Woolway et al., 2019).

An increase in the air temperature during summer will cause an increase in the water temperature. As the water temperature increases, dissolved oxygen levels decrease, and many aquatic species will be negatively affected.

Siltation will also reduce the area of the lake, leading to increased competition for available resources. Many spawning habitats require a specific sediment size (e.g., gravel) and too fine a sediment can end up smothering the eggs and other benthic creatures. Too much sediment deposition can also bury habitats[6].

More rainfall during the monsoon of the preceding year leads to loss of nesting habitats for the Bengal Roofed turtle. Sirsi et al. found that the number of nests of *B. kachuga* in the Chambal river was negatively correlated with total precipitation in the preceding year. Total precipitation may affect the amount of nesting habitat available and the availability of other limiting resource (Sirsi et al., 2017). It will lead to a decrease in the number of nests for turtles and a decrease in the turtle population.

[6] https://www.fondriest.com/environmental-measurements/parameters/hydrology/sediment-transport-deposition/

Silt brought down to the lake has proved to be beneficial for migratory birds, but its impact is now going into reverse. High-intensity rain is resulting in excessive siltation, filling shallow water bodies and eventually turning such areas into dry banks – the process is already underway.

The increase in temperature in winter may be detrimental for migratory birds. With significant climate warming, migratory birds have shown different population trends relative to resident species, with the former declining rapidly and the latter increasing. The role that climate change has played in these observed trends is not well understood, yet mechanisms that determine range boundaries of migrants suggest that they may be particularly vulnerable to climate change, especially during the non-breeding season (Clark et al., 2020). Likely impacts include shifts and significant constraints in their non-breeding and breeding distributions.

As high-intensity rain becomes a more frequent phenomenon, the increased organic load washed from the catchment and tourism areas may affect the water quality for various species, including the keystone species, the Red-Crowned Roofed turtle *(Batagur kachuga)* and the Golden Mahseer, endangering their long-term survival. The deeper areas of the lake, which are preferred habitats of aquatic species such as the Mahseer, are rapidly becoming shallower and filled with silt. Any new sediment load flowing into the lake is eliminating the deeper water habitat and the species dependent on it. Also, with the increase in temperature, the habitat conditions of the Mahseer will be impacted as the species requires cold water for breeding and survival. As the lake area decreases and dry banks increase, the habitat of migratory birds and turtles is narrowed down.

Adaptive capacity

Presently the overall adaptive capacity of the climate-sensitive habitat is generally much lower than what it needs to be to cope with the projected climate change impacts. The increase in temperature and precipitation, coupled with the increased organic load and the shrinking in size of the lake, will reduce the adaptive capacity of the habitat. In the future, it may not be a destination of choice for migratory birds due to the lack of a favourable temperature. The current management arrangements are complicated and not coping well with current challenges, and they are definitely not adequate for addressing the very significant future changes that are projected.

4.4 Asset 3: Aquatic grasses

Renuka Wetland is a vital habitat for terrestrial and aquatic organisms, and it is also the winter home of a wide range of migratory bird species. Aquatic grasses are a critical part of the wetland ecosystem; they provide food and habitat for a wide diversity of aquatic species and birds. They also help keep the water clear and healthy by absorbing nutrients, trapping sediments, reducing erosion and adding oxygen.

Exposure

The Renuka Wetland ecosystem is directly and indirectly exposed to the projected climate changes. The overall productivity of the aquatic ecosystems is directly impacted as it is regulated by temperature. Increases in water temperature will cause a shift in the thermal suitability of aquatic habitats for resident species. The aquatic vegetation, especially the macrophytes, is vulnerable to changes in climate since macrophytes represent the keystone species of aquatic ecosystems. Thermo-tolerant species such as *Hydrilla* and *Myriophyllum* spp. are likely to be favoured, but emergent species such as Typha have been found to increase with increases in temperature up to a threshold of 3°C to 7°C above ambient[7].

Sensitivity

Aquatic plant species are very sensitive to increases in temperature and alterations in the rainfall regime. Those changes directly and indirectly affect the growth, productivity and distribution of terrestrial and aquatic vegetation. The increase in temperature is already changing the distribution and abundance of aquatic grasses and favouring some species in Renuka Wetland, such as *Hydrilla* and *Typha* spp. Silt runoff into the lake alters the nutrient loading and is likely to limit the habitat distribution and diversity.

[7] Bhupinder Dhir Status of Aquatic Macrophytes in Changing Climate: A Perspective, Journal of Environmental Science and Technology 8 (4): 139-148, 2015, ISSN 1994-7887 / DOI: 10.3923/jest.2015.139.148.

Impacts

The shift in the temperatures and precipitation due to climate change may shift the species range in Renuka Lake. The aquatic plant species that have higher temperature threshold value will be favoured, and these mainly include thermo-tolerant free-floating and submerged macrophytes (*Hydrilla* and *Potamogeton* spp.) (Bhupinder Dhir, 2017).

During the monsoon, the increased intensity of the rainfall has led to increased siltation, which in turn has increased turbidity in the lake. Light attenuation by inorganic turbidity decreases the fraction of light absorbed by photosynthesising organisms in lakes (Donahue & Molinos, 1994). Therefore, it will have a varied impact on the aquatic grasses at different levels of the lake. The increasing trend of eutrophication in the lake is likely to impact the growth of aquatic grasses negatively, which will lead to the loss of habitat.

During winter, the increase in temperature can influence the length of the growing season, with consequent increases in bacterial and phytoplankton productivity as warming generally stimulates aquatic plant growth but reducing the light penetration and restricting growth of grasses. The filamentous alga *Spirogyra* is already common in winter, and warmer temperatures are likely to increase its growth.

Increased temperatures in summer may lead to an acceleration in the drying of the lake periphery, thereby leading to low output. With increased summer temperatures, there will be increased incidences of harmful algal blooms. Toxic blue-green algae prefer warmer water. Warmer temperatures prevent water from mixing, allowing algae to grow thicker and faster in surface waters. These algal blooms absorb sunlight, further increasing the water temperature and promoting blooms[8].

An increase in temperature during winter will increase the threat of invasive species expanding their geographical range and dominance (Adrian et al, 2009). Increasing extreme events (e.g., floods, drought, and wildfire) also facilitate invasions by invasive species. Climate change-induced alteration of the ecosystems due to increased rainfall or drought may present new opportunities for invasive species.

Adaptive capacity

Climate change impacts aquatic grasses in various ways. Increased temperature and precipitation affect vegetation and plant physiology. Increased organic nutrient load and turbidity impact the health and distribution of species. The threat of invasive plants due to the increase in temperature is one of the challenges that are unfolding at Renuka Wetland. At present the adaptive capacity to those changes is very low. The biggest challenge is the rapid pace of the eutrophication of the lake. The entire wetland ecosystem is threatened.

The management and monitoring of the sediment load entering the lake is missing. There are no data and knowledge about this critical change. Aquatic ecosystems have a limited ability to adapt, and the management systems in place are not coping.

4.5 Asset 4: Golden Mahseer

The Golden Mahseer has suffered severe population declines in much of its distribution range, and it is now listed as Endangered on the IUCN Red List. The Mahseer *(Tor putitora)* is endangered across the Indian Himalayan biodiversity hotspot. Multiple human stressors compounded by climate change have significantly depleted their populations. Already the species is in serious trouble and all projections do not favour the continued existence of the Renuka Wetland population.

Exposure

With increased temperature, Mahseer is directly exposed to various stressful conditions. Exposure to temperature-related stress can elevate physiological stress and increased metabolic demands, which directly affect growth, survival, reproduction and productivity. The Mahseer has limited tolerance to temperature extremes. The projected changes in temperature and precipitation will impact the spawning of the Mahseer. The changes in the climate will bring about flooding, high precipitation, drought and other climatic variables, exposing the fish to various challenges. Exposure to changed hydrographic features of the lake such as decreased depth will be particular severe for the species. Increased silt flow leading to increased shallow waters could jeopardise food web processes, thereby impacting its natural food availability.

[8] Climate Change and Harmful Algal Blooms https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms.

Sensitivity

The Mahseer is a sensitive species that cannot tolerate significant changes to its habitat. It has strict habitat requirements including cold water and high levels of dissolved oxygen. For the Golden Mahseer the ambient water temperature for breeding is usually 18°C to 22°C, and the spawning grounds are characterised by water temperatures varying from 11°C to 30.5°C. Flooding and soil erosion will pose a risk to the breeding habitat as the preferred shallow water will become highly silted. During the spawning period, silt deposition may kill eggs and fingerlings. Drought during breeding months can reduce access to the breeding sites.

Impacts

Climate change will negatively impact cold-water fish species such as the Mahseer. Increased temperatures can affect fish directly – their physiology, growth and behaviour.

The projected significant increases in surface water temperature during summer will pose a risk to the conditions at the Mahseer's habitat. The species requires cold water for survival, with a thermal habitat preference within 13°C and 30°C (Joshi et al., 2019). Mahseer require cold water for spawning during the monsoon, and the spawning grounds are characterised by water temperatures varying from 11°C to 30.5°C. The projected increases in temperature will shift conditions beyond those ranges, detrimentally affecting the Mahseer fish population of Renuka Wetland.

Water temperature has the most influential effect on the gonadosomatic index (GSI) of both sexes of Golden Mahseer. The optimal water temperatures for breeding in the species are usually in the range from 18°C to 22°C. The increased temperature is an important and relatively stronger determinant of ovarian maturation in female fish (Sarma et al., 2018), though there is no evidence of temperature-dependent sex determination in this species. With the increase in temperature, the metabolic rate also increases. Thus, the Mahseer will need more oxygen to support their elevated metabolism, but they may not be able to get it from the warmer oxygen-poor lake water.

During the monsoon, the impact of increased silt flow on breeding will be high as shallow water may become highly silted. High silt loads in the spawning grounds may lead to mortality of eggs and fingerlings.

Adaptive capacity

As the lake is slowly being filled with sediments, leading to a decrease in size and an increase in shallow areas, the habitat of the Golden Mahseer and its adaptive capacity are under threat. Also, seasonal climate changes (increasing in temperature and precipitation) may have long-term effects on the species. There are strict habitat requirements of Mahseer which comprise cold water, a high level of dissolved oxygen and habitat heterogeneity, with availability of in-stream pools/deep water storage and grounds that are conducive for spawning (Sarma et al., 2016). With no management plan and low institutional and financial support, the institutional adaptive capacity is low.

4.6 Asset 5: Turtles

The *Batagur* and *Nilssonia* spp. turtles found in the deep waters of the Renuka Wetland (with terrestrial nesting sites) are the most threatened freshwater turtles in India. The Red-Crowned Roof turtle, *Batagur kachuga,* is listed as Critically Endangered on the IUCN Red List of Threatened Species. *Nilssonnia gangetica* and *Nilssonia hurum* are both listed as Endangered. The Red-Crowned Roof turtle is listed in Schedule 1 of the Indian Wildlife Protection Act, 1972 and in Appendix II of the Convention on International Trade in Endangered Species (CITES).

Exposure

Climate change could lead directly to loss of habitats, affect food availability, reduce or change the prey base and affect individual growth rates. Changing lake water levels and dry banks could have major impacts on access to suitable nest sites and habitats.

Sensitivity

The temperature increase may directly bring about small changes as the species is known to survive in higher temperature conditions. The increase in precipitation is the real threat as it may lead to the destruction of the habitat. The increased rain intensity and volume are leading to faster degeneration and eutrophication of the lake.

Impacts

The high-intensity rain during the monsoon leading to increased silt deposition will further reduce the habitat. With the shrinking of the lake, the availability of suitable food in the future may be a concern, with consequences for population numbers.

The decrease in rainfall during the dry season may lead to a decrease in the underground spring discharge output because the outer periphery of the lake is already filled up with silt. The low spring discharge may lead to quick drying out expanding the area of the dry surface. This may lead to loss of habitat and a decrease in food availability.

Shifts in temperature will lead to changes in the reproductive period as turtles require specific temperature triggers for nesting. Flash flooding and more rainfall during the monsoon of the preceding year led to the loss of nesting habitats and food resources of the Bengal Roofed turtle (Sirsi et al., 2017). Fewer nests will result in a decrease in the turtle population (Chelonian Conservation and Biology, 2017).

Adaptive capacity

The accelerated decrease in lake size and the increase in shallow areas will reduce the habitat of all the Renuka turtles. The species have a low adaptive capacity to these changes. No comprehensive management strategy is in place that addresses the conservation needs of these species, and the necessary research to understand adjustments required to maintain the habitat is not being conducted. There is low institutional and financial support for the species.

4.7 Asset 6: Tourism

Renuka Wetland attracts recreational and religious tourism amounting to around 3,00,000 pilgrims during the November religious festival and during the remainder of the year – but no precise records are kept. The Wetland is considered holy and Renuka temple is a popular religious pilgrimage destination situated near the lake. The Lake's scenic beauty and calmness also attracts tourists throughout the year. Boating and the mini zoo are popular recreational options for tourists. The tourists visit the wetland during summer as well as winter as it is the site of an annual fair. Renuka Wetland tourism is strongly promoted by various authorities and religious groups – with no consideration or assessment of the carrying capacity of the site and the impacts that tourism and related facilities are having on the features tourists come to enjoy.

Exposure

The tourist destination and its facilities are directly exposed to the impacts of increasing high-intensity rains and their adverse effects, including landslides, storms and floods, and to the projected increases in temperature.

Sensitivity

Exposure of the highways leading to Renuka Wetland can cause delays or interrupt the movement of tourists. Cloud bursts and heavy rains with increasing intensity and frequency pose a severe threat, damaging or washing out the tourism facilities and infrastructure, and potentially places tourists at risk. There may be a significant reduction in the number of tourists with the expected increase in the number of extreme events. Adverse news after some extreme events may increase the concern for tourists in terms of security and protection about the destination itself.

We are dealing with two tourist types in Renuka Wetland - general and religious - and the perceptions and behaviour of each will be somewhat different. General tourists will look for favourable weather conditions such as precipitation and temperature while religious tourists are less concerned with the weather unless it is life threatening. All tourism activities are sensitive to abnormal weather conditions.

Impacts

Extreme weather events like floods, drought and wildfires can influence tourist activity as well as their safety and linked infrastructure. Climate change will have several impacts on the tourism industry. Unfavourable climate conditions could become the reason to avoid Renuka Wetland in the most affected seasons. High-intensity rain can lead to landslides, washing away sections of roads and blocking access to the site. As this is a mountainous area, increased rain leads to blocked roads and disruption in transport and to fewer tourists during summer and the monsoon, leading to loss of income. It will have an impact on livelihood activities related to tourism during these seasons.

Increases in summer temperature at Renuka Wetland will have little impact on visitor numbers as tourists prefer the much cooler options available in Himachal. The summer temperatures at Renuka Wetland tend to be higher than those at most of the other tourist destinations in Himachal. The increase in temperature will be detrimental for tourism during the monsoon as increased temperatures coupled with high humidity are likely to impact on visitor numbers.

Increased temperature due to climate change during post-monsoon and drier winters will lead to more favourable temperatures and conditions for tourism. Renuka Wetland is likely to attract more tourists during winter. An increase in visitor numbers at this time may put additional stress on tourism facilities and on the capacity of environmental management, e.g., increased pollution and solid wastes. Favourable temperatures during the annual religious fair may encourage more religious tourists to the site. Uncontrolled tourism will have potential negative impacts on Renuka Wetland and its catchment. The impacts of climate change may also impact tourism indirectly: it may also reduce the attractiveness of Renuka Wetland as a tourist destination in the future during summer and the monsoon or indirectly affect the quality of the experience, creating adverse perceptions after some extreme event.

Important indirect impacts on tourism – at least for the general tourist – will relate to reduced environmental quality and the area's conservation values and amenity.

Adaptive Capacity

Increased temperatures and extreme events are some of the challenges that tourism operators and tourism will face. There is a low adaptive capacity for dealing with these changes. The environmental quality will continue to deteriorate. The present capacity for managing water pollution and solid wastes is very low. The lake-based ecosystem cannot handle the current and potential increases in tourist pressure. Little infrastructure is in place to support tourism and existing facilities are located in the eco-sensitive zone which is degrading the very features tourists wish to visit.

4.8 Renuka Wetland vulnerability assessment conclusion

The vulnerability assessment reveals that the lake and the fragile landscapes of the Renuka Wetland are highly susceptible to current and projected climate changes and that associated impacts are likely to have irreversible consequences on the area's biodiversity. They may even lead to a total loss of the wetland system in its current form. High temperatures, precipitation, incidences of floods, sedimentation and droughts all translate into multiple stressors contributing to the vulnerabilities of the five assets across aquatic and terrestrial ecosystems. The entire catchment and the Renuka Wetland will be impacted at different scales, directly or indirectly, leading to very high vulnerability. To be sustainable, the area requires a very significant increase in investment and management attention.

A comprehensive response to climate change is needed through implementation of appropriate adaptation plans to enhance Renuka wetland's resilience to current and projected changes. Those adaptation measures should be built into the overall Ramsar Site management and reviewed on a regular basis in keeping with the government's normal budgetary cycle.

5 ADAPTATION PLANNING

The vulnerability assessment of Renuka Wetland provides the framework of impacts and issues to be addressed in the adaptation planning process. Projected changes in climate, particularly the increases in temperature and precipitation, will have significant impacts on Renuka Wetland. Adaptation and associated management interventions in response to the vulnerability assessment are essential to enhance ecological resilience in the wetland area and to ensure its future as a Ramsar site with global conservation values. The current conservation and management investment is insufficient to address existing, let alone future, challenges. A well co-ordinated and resourced approach is needed to rehabilitate and maintain the lake.

Many of the adaptation measures proposed in this section may be repeated several times because they represent a common response to different aspects of the climate change threats and impacts. For example, measures to address impacts of rainfall on soil erosion in the catchment are repeated when considering increased sedimentation and siltation in the Lake. To reduce repetition a measure which has already been described will be referenced but not detailed in sections which follow. The detailed Adaptation Planning Matrices for each of the target assets are attached as the source material of this report (Annex 3).

5.1 Catchment

The biodiversity of the wetland catchment is very rich. The southern slopes are steep, whereas the northern side is characterised by gentle slopes. The hills that surround the lake on its northern and southern sides are covered with sub-tropical dry deciduous forests.

In an effective adaptation response to the degrading Renuka Wetland catchment, the long experience in Himachal Pradesh with social forestry will need to be reviewed and lessons applied to ensure sustainability. This catchment is a special case because its health and maintenance is a prerequisite to the continued existence of a downstream biodiversity and cultural site of global and national importance. While social forestry principles require that communities are engaged in catchment forestry management for the provision of fuel and other goods to meet basic needs at rural household level, and the provision of employment and income generation in the community, in this case the overriding objective must be the rehabilitation of the biodiversity and stability of the catchment. It is very important that local communities be involved in restoring the catchment but benefits and uses will need to be constrained by the requirements of conserving the Renuka Wetland.

5.1.1 Increase in rainfall during SW monsoon

Increased monsoon rainfall with high intensity will have a high impact on the catchment, leading to higher soil erosion over the slopes, making them more prone to landslides and causing siltation of the downstream wetland. Once the top fertile soil erodes it will lead to further degradation of catchment forest cover, and the water-holding capacity will decrease. This, in turn, is likely to lead to increased water runoff from the hill slopes and lower ground water recharge and spring output.

ADAPTATION MEASURES

Increased gap-filling afforestation in the catchment areas where there is a thin tree/canopy cover or gaps. Soil erosion can be checked to some extent by intensive planting and rehabilitation, but the impact can be only partially avoided as it is a mountainous catchment with steep slopes. The effectiveness of the adaptation measure will grow with time as the trees mature, and so this measure will take time and intensive up-front investment.

Afforestation in catchment forests can positively influence the microclimate, which can enhance the resilience to climate variability locally to some extent. Planted forests work as carbon sinks on degraded soils, thereby mitigating the impact of climate change.

The activity will be conducted by the Forest Department as part of their regular mandate and programme. The budget may need to be drawn from local and national resources, given the international importance of this site and the need for ongoing monitoring and maintenance. The work can be integrated into the normal DOF work programme.

Obstructing the surface water flow entering into the lake for silt control and increased ground water recharge can be achieved through different measures including bunding, diversion drains, contour trenches, stone walls, retaining walls and check dams as silt traps. This will maintain flows from the springs feeding into lake. Most of the activities are low-cost measures barring a few which may require additional budget allocation. The Forest Department already has experience in undertaking some of the measures. Little R&D is needed although thorough ground survey is required to ensure the works are well sited and conducted on an integrated watershed wide basis. This would best be a collaborative programme involving DOF and agencies such as the HP Watershed Department, the Department of Rural Development and the national Integrated Watershed Management Programme (IWMP) implemented by Department of Land Resources of Ministry of Rural Development. The main objective of IWMP is to restore the ecological balance in target areas by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water including attention to community mobilisation and social organisation.

Construction of siltation and settling pools in the catchment area wherever possible. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by improving and stopping the runoff from the catchment area. These measures are site-sensitive and need proper site identification, particularly in hill areas otherwise they can become counterproductive or even damaging to the environment. The impact will be partially avoided and will need regular maintenance for these pools to function effectively. It should be implemented by Forest Department with effective co-ordination with the Watershed Department for technical feasibility and execution. It is a labour-intensive activity, with labour costs covered under the Mahatma Gandhi National Rural Employment Guarantee Act 2005 (MGNREGA).

Bio-engineering methods for erosion control: Bio-engineering solutions need to be adopted for soil stabilisation and control of sediment runoff, particularly on mountainous slopes. Bio-engineering techniques can be used to enhance slope stability, e.g., brush-mattress structures, Wattle (wicker) fences, long brush barriers, and Fascines are some of the bio-engineering measures that can be undertaken for slope stabilisation. These are low-cost measures, but they are labour-intensive, with the costs covered under MANREGA. In this way, the Forest Department can undertake such activities with less impact on its annual budget.

Drainage lines that carry runoff and sediment flow need to be re-established to reduce sheet runoff and erosion. This activity might involve rehabilitation of natural drainage corridors that have become filled with soil or establishing new lines in areas experiencing increased intensity of runoff. While hard structures may be needed, requiring special budget allocations, the overall principle of using nature-based measures in the Renuka Lake adaptation plan should be followed. Even when hard structures are essential, a hybrid integrated green and grey approach should be taken. This activity will be conducted by the Forest Department in collaboration with the Watershed Department.

Terracing in the slope areas where maximum runoff occurs: Terracing is already common in Himachal, mostly for agricultural fields, and is very effective in reducing erosion on steep slopes. On steep areas with poor and thin soil layers, it can be an effective adaptation measure for reducing immediate runoff and improving ground water percolation. It is highly labour-intensive, and so the initial costs are quite high, but these activities can be planned for the long term, with labour costs covered under MGNREGA.

5.1.2 Increase in temperature

Increase in temperature during winter: The growth of certain plants that need a low winter temperature may be impacted by the increase in temperature. Species favouring a milder or warmer temperature may alter the biodiversity of the forest.

Increase of temperature during summer: The significant increase of temperature during summer will lead to dryness and increased mortality in forests and changes in biodiversity as species intolerant of heat stress will be lost from the area to be replaced by those that can cope. Increased summer temperatures are likely to be accompanied by more frequent fires and tree mortality.

ADAPTATION MEASURES

Increasing the local species having high Leaf Area Index (LAI) values to make forests cooler: Dense canopies, with high LAI values, can block over 95% of the visible light from reaching the Earth's surface (Bonan, 2008), keeping the air and soil beneath the canopy cool during the day. In temperate forests, this effect plays a major role in protecting temperature-sensitive species from the impacts of climate change (De Frenne et al., 2013). The establishment of denser canopies in tropical forest through enrichment planting of appropriate native broad leaf species can drive change in microclimate. The activity would be undertaken by the Forest Department, which has all the required expertise, but it is a long-term investment and will take time to bear fruit.

Increase tree species diversity to reduce risk: Increasing the tree species diversity within the catchment forests increases their adaptive capacity and resilience. Special attention is needed to local species which are more resilient to change and therefore most likely to persist. This measure will be implemented by the Forest Department, which will draw from its existing and supplementary budget as required for the up-front investment. Research and development work will be required to identify the most appropriate native tree species to use in this reforestation work.

Planting species that are more resilient to high temperature: The catchment rehabilitation programme should include planting species with deeper root systems, which are more heat tolerant to ensure that the cooling function of trees is maintained even during long-lasting heatwaves. As in the adaptation response to increasing temperatures during winter, an increase in tree species diversity is required, with deep-rooted trees that can withstand heat waves. Special attention is required to increase the heat tolerance of seedlings by prior exposure to moderately high temperatures in nurseries. Establishment of a substantial and well managed nursery at an appropriate location within the catchment will be required. These measures will be implemented by the Forest Department within its existing budget and staff resources.

Emphasis on techniques that increase soil moisture: Although the direct effects of high temperature on trees can be severe, extreme high temperatures when the soil moisture retention capacity is high tend not to have long lasting effects. Techniques such as mulching around the planted saplings and ground cover species along with tree species enrichment can help increase soil moisture.

Early detection and rapid eradication response toward terrestrial invasive plant species by physical removal or hand pulling: There are already noted invasions of *Camara lantana* and *Adhatoda vasica* in the catchment mentioned in the management plan, which is likely to be aggravated by climate change. The eradication and physical removal of invasive exotics is a labour intensive and on-going task to be undertaken by Forest Departments in collaboration with the Wetland Authority.

Genetic engineering of trees: Genetic engineering of trees has potential to provide rapid improvement in heat and drought tolerance of trees by utilising introduced genes gained from research on other plant types. This measure will be carried out by the Forest Department with institutional support from various genetic research institutes. Care will be needed to ensure that only native species are used and not to introduce invasive species. The cost will be high and involve extensive R&D. This activity can only be undertaken if a special purpose research budget is allocated.

5.1.3 Flooding

Floods will degrade the catchment, leading to increased incidences of runoff, high soil erosion and landslides and downstream loss of lake area and habitats.

ADAPTATION MEASURES

The main strategy for addressing the existing and projected flooding will be ecosystem-based adaptation (EbA). EbA is the use of biodiversity and ecosystem services as part of an overall strategy to help nature and people to adapt to the adverse effects of climate change.

Bunding: A priority for the Renuka Wetland catchment is to stabilise the fragile mountain slopes through reforestation, contour bunding and, in appropriate areas, the introduction of agricultural terraces. Bunding involves making cuts into steep slopes

to establish surfaces that are supported by mud and/or stone walls. As these terraces are positioned perpendicular to the flow of water, they allow the water to infiltrate the soil slowly. Erosion is reduced and soil retained, while soil moisture is improved, enhancing overall vegetation productivity. Contour bunding is a proven sustainable land management practice for marginal, sloping and hilly land where the soil productivity is low. It is a widely adopted tradition practice by communities control soil erosion, promote water retention, and increase crop production. It is simple to implement, costs little, and makes the maximum use of local resources. It is important to regularly check and maintain the bunds to allow the soil to collect.

Conservation ponds: In certain areas conservation ponds can be established as an EbA measure to provide a buffer against rainfall-related events such as flooding and drought. During the dry season and prolonged dry spells, the ponds serve as reservoirs for water, while they help prevent excess water runoff during the monsoon. The ponds could be established closer to the lakes as a series of terraced wetlands with biodiversity values. Their siting and feasibility will need to be piloted and evaluated for wider application.

Afforestation along flood channels retain rainwater and reduce discharge: Flood channel afforestation will be undertaken by the Forest Department and collaborate with the Watershed Department on water conservation activities such as contour bunding, check dams and vegetative barriers, terracing, diversion drains, trenches and retaining. All the EbA watershed rehabilitation activities will be labour intensive and require special budget allocations by the Watershed Department.

5.1.4 Drought

Droughts coupled with high temperatures will lead to higher thermo-evaporation. Little or no rainfall will reduce the percolation of water, leading to poor recharge of the catchment area. The water level in the lake is not directly dependent on the rainfall but on the water from underground springs. With less rainfall and less ground water recharge, the springs and aquifers will also dry up, leading to decreased lake water levels. Droughts will lead to higher mortality of flora, and the catchment area will have lower food availability. This will cause decreases in the populations of some forest species and even local extinction of species that are unable to cope with heat stress and lesser water availability.

ADAPTATION MEASURES

Water and soil conservation measures in the catchment: As in the general response to increased temperatures and more intensive rainfall, increased tree cover will lead to better ground water recharge and water conservation. Similarly, measures to increase soil moisture and retention will help maintain the water table. Deep-rooted tree species and bio-engineering measures such as gully plugs, contour bunds, and check dams promote infiltration and ground water recharge. Additional resources may be needed for those soil and watershed activities. They will be implemented by the Watershed Department through effective co-ordination with the Forest Department. Very little R&D is required as the Watershed Department undertakes such activities on a regular basis.

Planting of local drought-resistant palatable varieties: Palatable varieties of plants serve as fodder for wild animals during drought conditions and will enhance resilience. Planting will be undertaken by Forest Department for afforestation activities with no extra budget required. Fodder trees can be linked to increasing the green cover in villages using the catchment area so that the villagers have less need to exploit the forest resources for their livestock during droughts.

Encouraging evapotranspiring trees capacity to recharge the atmospheric moisture: Increased tree cover will lead to better ground water recharge increasing evapotranspiration which in turn contributes to local rainfall and in distant locations, depending on the wind speed and direction. Trees have the capacity to capture and redistribute the sun’s energy and thus provide cooling. The afforestation will be undertaken by the Forest Department, and the water conservation activities will be carried out by the Watershed Department.

Appropriate tree and understorey species should be selected according to the site suitability: Factors to be considered when selecting species include growth rate, site requirements, climatic suitability, genetic variability, biodiversity and wildlife value and promotion of erosion control. Trees serve to buffer understorey environments from climate extremes. Buffering may promote micro-climates that function as micro-refugia and favourable local climate conditions. Altering the micro-climate by enhancing the forest canopy cover within the catchment and outside is a key adaptation strategy for most climate changes.

5.1.5 Fire

The increase in temperature and drought conditions will increase the risk of fire. Already Himachal forests face severe fire incidents each year, especially during summer, and in future fire incidents are likely to increase across the catchment. Consequences of forest fires include forest stand mortality, loss of wildlife and loss of food availability. There will also be a loss of soil moisture with a negative impact on ground water recharge capacity. As immediate after effect of massive fire is increased runoff and erosion impacting ground water. Watershed rehabilitation and maintenance activities will make the catchment more resilient to ground water impacts of fire. They will increase percolation and recharge and help control erosion after forest fires.

ADAPTATION MEASURES

Landscape flammability can be reduced through afforestation species selection: Strategies to increase resilience include creating multi-aged stands and favouring drought and fire tolerant trees in existing stands, such as the oak species. This will be a long-term measure and require also a long-term strategy to execute. Forest fires seldom occur in the deciduous broad-leaved forests of the temperate zones, so maximising the local broad-leaf deciduous palatable species in the forest will be an important element in the strategy.

Integrating all activities and actors related to fire management such as prevention, preparedness, suppression and restoration, into one co-ordinated process of fire management, planning and implementation will be essential. Such activities will be taken by Forest Department with the active participation of Fire Department empowering the Forest Department with training on the latest strategies and equipment. The Forest Department has an annual budget for fire-control activities. They involve creating fuel breaks (e.g. non-vegetative lines, thinned areas, or bodies of water) to slow the spread of wildfire and protect areas of high concern or value. A fire-line or break is defined as a narrow portion of a control line from which inflammable materials have been removed by scraping or digging down to mineral soil. Firebreaks can be successful in stopping the spread of a creeping fire.

Early warning: Given the serious impact of fires on biodiversity and on the general condition of the Renuka catchment, it will be important to set up a forest fire monitoring and early monitoring system in areas known for recurrent fire and which have been identified as hot spots for projected high temperatures and drought conditions. Early warning teams can be set up by Forest Department in close co-ordination with local communities for early detection and dousing of fires. This measure has a limited scope without a guarantee of complete success in the detection of forest fires. It will involve additional budget allocation if community members are involved.

5.2 Shallow water and dry bank habitats

Two habitats in the Renuka Wetland are of special conservation importance. One is the shallow water habitat for migratory birds created by the silt brought down by the seasonal streams and the other is the dry bank areas providing nesting ground for turtles.

5.2.1 Increase of rainfall during SW monsoon

Over decades, the silt brought down to the lake was beneficial for migratory birds but now heavy rainfall events and increasing siltation is filling the shallow water areas. With projected increases in rainfall those areas will become dry banks. Already, eutrophication in the lake is high and the increases in sediment and nutrient load will reduce the quality of shallow and deeper water habitats. Suitable habitat for migratory birds and turtles will be reduced and the overall lacustrine ecosystem will be transformed into marshland.

ADAPTATION MEASURES

Once again forest rehabilitation in the catchment areas vulnerable to erosion will be the central adaptation strategy accompanied by wide adoption of EbA measures to improve the watershed conditions. The Northeast area of the Renuka

Wetland catchment has been identified as the most vulnerable to soil erosion, with the highest sediment load to the lake originating from there. This area should be a focus for soil erosion reduction measures. Reducing the projected excessive flow of silty water entering the lake is essential. In areas of high/steep slopes and poor and thin soil layers, soil erosion control can be difficult. The design can consider bio-engineering methods for gully erosion control, drainage lines that carry runoff and sediment flow. Various forms of bio-engineering need to be considered such as drainage channels, gullies connecting to natural/artificial waterways and leading to streams or rivers downstream. Bags and "logs" made of biodegradable geotextile can be widely applied. This measure will require specialist expertise so collaboration with research institutes or other organisations experienced in this process need to be established for training and demonstration. The geotextile bags and logs are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channels. The method is a straightforward, low maintenance technique for trapping silt.

Construction of siltation dams and settling pools in the catchment area wherever possible will be implemented by the Watershed Department with effective co-ordination of the Forest Department. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise it can become counterproductive and environmentally damaging. They are best accompanied by flow retardation and deviation measures along existing drainage lines using planting and contour bunding.

These catchment measures can be accompanied by **the removal of accumulated sediments and organic matter in the lake:** This can be done through dredging with excavators or the use of de-silting pumps. Removal of sediment from the Lake will be undertaken by the Wetland Authority with the Forest Department, Wildlife Department, and Mandir community. The cost of dredging and de-silting will be significant and will require special purpose budget allocation. Due diligence needs to be undertaken before doing any dredging and only undertaken under expert supervision. By de-silting, the original lakebed is disturbed which may have far-reaching adverse effects on the habitat of species and the hydraulic performance of the lake. It should be done progressively in annual increments in small sections of the shallow areas of the Lake, leaving the rest to the shallow areas undisturbed until another year. The most visible effect will be the increase in percolation rate resulting in heavy seepage losses through the lakebed. It will directly have a long-term positive impact with long-term benefits of adaptation.

Creating a balance of shallow water habitat for migratory birds & dry bank areas: When planning the de-silting and manual removal of accumulated sediments, attention should be paid to the creation and restoration of these key habitats for birds and the nesting grounds for turtles through soil and water conservation activities and careful location-specific interventions to allow accumulation of sediment in some areas and maintenance of shallow waters in other areas. The most promising areas to begin experimenting with this work is where streams and springs enter the lake.

Terracing in sloping areas where maximum runoff occurs: Terracing is already practiced in Himachal mostly for agricultural fields and is a proven traditional measure to control erosion and promote infiltration. The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and in close co-operation with the Flood and Irrigation departments. It will require budgets for terracing the steeply sloping areas and reducing run-off into the Lake. This adaptation activity will take some time to complete and become operational.

5.2.2 Increases in temperature

Increasing in temperature during summer: The increase in temperature will dry the filled-up silted areas faster, creating dry banks. It will lead to increased evaporation of lake water and may exacerbate algal blooms. It will have a direct impact on food availability and is likely to promote changes in the biodiversity of the lake. Algal blooms cause anoxic conditions, altering the plant species composition and biomass, leading to fish kills, food web disruption, toxin production and degradation of recreational areas.

Increasing temperature during the NE monsoon will continue to dry out the banks. Turtles are hole nesters, needing muddy banks, and eventually it will not be possible for them to excavate nests. This will lead to a shift in the nesting and hatching period and will reduce the active reproductive period of turtles. In the shallow water habitat of migratory birds there is an increased risk of invasive grasses and reduced area of the lake due to siltation and drying. The increase in weeds will reduce the extent and quality of the habitat in this area of the lake.

ADAPTATION MEASURES

Tree cover shading the banks of the lake and air injection will have cooling effects: Impacts of increased temperature can be reduced by deep-rooted trees lining the lake banks to provide shade, reduce evapotranspiration and an enhance the ability to withstand long-duration heat waves (Teuling et al., 2010, Zaitchik et al., 2006). Increasing tree cover along the banks will take time to establish so benefits will be in the medium to long-term. High levels of thermo-evaporation can also be reduced by injection of air bubbles into the water. It is a high-cost activity, and a separate budget will be required though the measure can be started with immediate benefits. In summer the surface water heats up and becomes less dense. Below this surface layer, which is 3 – 4 m deep, the water remains cold and dense. Artificial de-stratification will happen when a bubble plume is injected in the cold deep layer. Consequently, the evaporation is reduced by balancing temperature gradients over the depth of the storage (Yara et al., 2019).

High thermo-evaporation can also be reduced by floating plants and wind breaks: Floating aquatic plants such as the Water Lily, Small Duckweed, Great Duckweed and Watermeal can reduce the evaporation of water by limiting the connection between the air and the boundary layer of the water. Duckweed can reduce evaporation up to 10% (Yara et al., 2019). This measure will be implemented by the Wetland Department in co-ordination with the Forest Department. It is a low-cost activity, and the adaptation measure can commence immediately. The wind is a key factor affecting the rate of evaporation from water surfaces. Planting wind break trees is an effective method of reducing evaporation losses (Yara et al., 2019). Wind breaks will be established by the Forest Department.

Improving lake water quality through aerators and phosphorous binding products: Aerators increase diffused oxygen in the water, reduce the incidence of algal blooms and reduce ambient temperatures. The activity will be taken by the Wetland Authority, and a separate budget will be needed. It will involve high capital cost and recurring electricity cost, and external experts will be required for installation. It is a one-time cost apart from regular maintenance costs. Phosphorous-binding products added to lake water prevent nutrients from stimulating algae growth.

External feeding of migratory birds during times of disruption to the habitat. When adaptation measures are being put in place, such as dredging, it may be necessary to supplement the food availability for the migratory birds until the habitat has been restored. It will be implemented by Wetland Authority in co-ordination with the Forest Department. It is a low-cost activity and can be started as soon as the feeding habitats for the birds is disrupted.

During the dry season, nesting areas can be kept moist by sprinklers: As drying out of the nesting areas becomes a significant issue, water sprinklers may be installed. The conditions of the muddy banks should be monitored to assess whether this will be necessary each year.

Hatching and breeding under captivity as a backup measure if the need arises: If it becomes evident that the nesting sites are being disturbed and lost, it may be necessary to implement captive breeding of the turtles and artificial hatching of the turtle eggs. It is an option that needs to be kept open as a backup measure so that the habitat loss does not end in species loss. It will be implemented by the Wetland Authority in co-ordination with the Wildlife Department. It is a high-cost activity and a separate budget is required for the adaptation measure. It will take time to implement and should only be started if the habitat conditions deteriorate and breeding failure in the turtles is evident.

Early detection and rapid eradication response for aquatic invasive species by physical removal or hand pulling will be necessary: The monitoring, eradication and physical removal will be undertaken by the Forest Department and the

Wetland Authority. It is a cost-effective process and will require regular monitoring and action on a continuous basis.

Increasing in spring water output by catchments rehabilitation and maintenance: The water level in the lake during the NE monsoon is totally dependent on ground water and springs. In order to address water shortages during the NE monsoon, it will become necessary to increase rainwater percolation and ground water recharge in the catchment using measures detailed in the section on catchment management. The spring flow should be carefully monitored to assess the effectiveness of the rehabilitation and protection measures.

5.2.3 Flood

Flash floods will increase the sediment in the lake, affecting the shallow water habitats as well as the dry banks, leading to a reduction of the size and depth of the lake.

ADAPTATION MEASURES

The most effective measures for flood management are likely to be through improving and rehabilitating existing damaged protective structures and bioengineering in the catchment. These measures were detailed in the earlier section on catchment adaptation. They include:

- Non-structural measures: flood warning and forecasting systems
- Structural protection measures in the catchment such as:
- Check dams and block ramps in drainage corridors.
- Terracing in the slope areas where maximum runoff occurs.
- Flow retardation: reservoirs (detention/retention basins).
- Flow deviation: construction of deviation channel.
- Acceleration of outflow: through pipelines or creation of new drainage corridors

These activities can be undertaken by the Forest Department with technical expertise from the Watershed Department and may require close co-operation with the Flood and Irrigation departments. It will involve a budget for setting up new flood management structures. Any structure that blocks the natural flow in drainage channels needs to be carefully assessed and sited to avoid ecological damage and biodiversity losses. Poorly planned artificial structures can preclude connectivity in water courses, leading to fragmented habitats, eliminate fish migration and reduce biodiversity.

5.2.4 Drought

Drought will have a negative impact on terrestrial and aquatic habitats, ground water recharge and lake water availability and quality. Shallow water areas may dry up, with increased dry banks and leading to ecological shifting or elimination of the habitats at the Ramsar Site.

ADAPTATION MEASURES

Infiltration and ground water recharge and increase in spring water output. Various EbA measures are available to increase ground water levels during the monsoon in preparedness for drought events that may follow. The catchment ground water recharge can be facilitated by tree planting or through structural measures such as bio-engineered gully plugs, contour bunds, dug-well recharge, percolation tanks, check dams and recharge shafts, depending on the site in the catchment and need. It can also be facilitated by evapotranspiration, trees recharging atmospheric moisture, contributing to rainfall locally and at distant locations. Cooling is explicitly embedded in the capacity of trees to capture and redistribute the sun's energy (Pokorný et al., 2010). The forest landscape rehabilitation will be undertaken by the Forest Department with complementary water conservation activities led by the Watershed Department. The immediate impacts of drought will be partially avoided, but the benefits of improving ground water infiltration will be felt in the long term.

De-siltation so that periphery of the lake has a larger water holding capacity, increasing tree cover in the peripheral area and expansion of trees shading the banks, especially deep-rooted species, are all measures required for building resilience to droughts in and around the lake.

5.3 Aquatic grasses

Aquatic grasses are a critical part of the ecosystem. They provide food and habitat for various aquatic species and birds. They also help keep the water clear and healthy by absorbing nutrients, trapping sediments, reducing erosion and adding oxygen.

5.3.1 Increase of rainfall during SW monsoon

With increased rainfall and soil erosion, turbidity in the water will increase, with a reduction in compensation depth below which light intensity is insufficient to sustain photosynthesis. During the SW monsoon, there will be a decrease in growth and productivity of aquatic grasses as the silt load increases with progressive reduction in the ecosystem services.

ADAPTATION MEASURES

Many of the measures outlined in earlier sections will help improve conditions for the growth and production of aquatic grasses impacted by increased silt. These measures are summarised here.

Stream bank erosion control measures. The purpose of stream and drainage corridor bioengineering is to reduce the runoff of sediments before they enter the lake ecosystem. The measures will reduce sedimentation and runoff in the upper reaches of the catchment and help increase the ground water level and maintain spring waters. The specific assortment of bank stabilisation measures will need to be adjusted according to the site characteristics. The measures include, for example:

- **Vegetated gabions:** Gabions are rectangular baskets made from a hexagonal mesh of heavily galvanised steel wire and filled with rocks and stacked atop one another to form a wall. Cuttings and seeds of suitable tree species are added to enhance biodiversity benefits, increase the gabion strength and provide flexible binding to the surrounding environment once the wire has corroded.
- **Vegetated geogrids:** consisting of alternating layers of live branch cuttings and compacted soil with geotextiles (natural or synthetic) wrapped around each soil lift.
- **Vegetated ripraps:** incorporate a combination of rocks and native vegetation in the form of live cuttings. Native vegetation improves fish habitats by creating shade, cover and an input of small organic debris to the stream. It will provide added bank protection through development of root mass and potential supply of fodder for local animal populations.
- **Geotextile fencings:** Silt fences are temporary barriers for retaining sediments and controlling erosion. They are made out of geotextile filter fabrics, woven together to create sheets of material with strength and permeability, enabling water to flow through while preventing sediments from moving downhill. Wooden or steel posts spaced regularly apart are used to support the fabric[9].

This range of measures will be set in place and monitored by the Watershed Department in co-ordination with the Forest Department and may require additional budget allocations.

Construction of drainage lines and diversions which carry runoff and reduce sediment flow. The adjustment of drainage lines to reduce sheet erosion may take different forms such as rehabilitating existing and creating new drainage channels, combined with revegetation and geotextiles so that silted water is diverted before it reaches the lake. Geotextile bags and logs are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice as part of the forest landscape rehabilitation. Forest gap filling and afforestation in the catchment, particularly along the flood channels, are particularly important to retain rainwater and reduces discharge. It is a straightforward and low-maintenance technique for trapping silt. The Forest Department will require a budget and expertise from outside, and so collaborations with appropriate research institutes or other organisations need to be established during the initial period of training and procurement of materials.

[9] How to Control Stream Bank Erosion | Soil Management"
https://www.soilmanagementindia.com/soil-erosion/stream-bank-erosion-soil-erosion/how-to-control-stream-bank-erosion-12-methods-soil-management/15683).

Construction of siltation dams and settling pools in the catchment area. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by rehabilitating the catchment area, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise it can become counterproductive and environmentally damaging. The siltation dams and pools will need regular maintenance to function effectively.

5.3.2 Increase in temperature

Increase in temperature during winter: Increased winter temperatures leads to an increase in productivity, but they may also facilitate an easier introduction of new and potentially invasive species into the ecosystem.

Increase of temperature during summer: Warmer summers lead to increased incidences of algal blooms. They may lead to an acceleration in the drying up of the lake periphery, thereby leading to low output. They will tend to increase the growth of aquatic plants, which could clog some parts of the lake, making boating difficult and causing water quality problems when the plants die and break down. There is also the risk of introduction of new invasive plant species that thrive in the warmer water temperatures. Eventually, these influences will speed up the reduction of the lake size and its transformation into a marsh type wetland.

ADAPTATION MEASURES

Adaptation responses to increased temperatures are covered in earlier sections of this chapter. They include:

- A management system for early detection and rapid eradication response toward aquatic invasive species. Physical removal or hand pulling is needed.
- Lake water movement through aerators or fountains.
- Application of phosphorous-binding products, which prevent nutrients from stimulating algae growth, in nutrient-heavy lakes and ponds.
- De-siltation so that the periphery has a larger water-holding capacity.
- Increase in spring water output by treatment of catchments.
- Increase in tree cover in the peripheral area.

5.3.3 Flash flooding

Flash flooding will have a negative impact on the aquatic grasses. It will lead to increased turbidity in the waters where the aquatic grasses grow with a reduction in compensation depth, below which the light intensity is insufficient to sustain photosynthesis. There will be a decrease in the growth/production of aquatic grasses as the silt load increases during this period. Runoff from catchment areas transports nutrients and sediments into lake ecosystems, which may affect the populations of aquatic organisms that compete with the grasses and reduce their area.

ADAPTATION MEASURES

All the measures outlined below will help increase the growth and production of aquatic grasses impacted by increased silt induced by flash flooding. They have been detailed in earlier sections of this chapter and include:

- Stream-bank erosion control measures to stop runoff sediments before they enter the lake ecosystem.
- Construction of drainage lines and diversions that carry runoff and sediment flows.
- Installation of silt trapping mechanisms before silt reaches the lake through bags and logs made from biodegradable geotextiles.
- Construction of siltation dams and settling pools in the catchment area.
- Forest gap filling and afforestation in the catchment, particularly along the flood channels, which leads to retention of rainwater and reduces discharges.

5.3.4 Drought

Since the spring recharge is dependent on the catchment recharge, any drought will have an impact if it is for a prolonged period. Droughts, when combined with raised temperatures, will lead to heat stress of plants and animals.

ADAPTATION MEASURES

The adaptation responses to potential impacts of droughts on the lake grass habitats have been described in earlier sections of this chapter. They include:

- Infiltration and ground water recharge and increase in spring water output.
- Emphasis on techniques that increase soil moisture.
- Pre-treatment of seedlings to enhance tolerance of heat stress.
- Genetic engineering of trees and ground cover.

5.4 Golden Mahseer

The Golden Mahseer, *Tor putitora* Hamilton, is one of the largest freshwater fishes of the Indian sub-continent. The Golden Mahseer is listed as Endangered on the IUCN Red List. The species has suffered severe population declines in much of its distribution range due to multiple human stressors, compounded by climate change.

5.4.1 Increase of rainfall during SW monsoon

The increase in rainfall during the monsoon may lead to less space being available for the Mahseer due to an increased silt flow impacting its natural habitat and food availability. Mahseer usually migrate up medium-sized streams to spawn in cooler fast-flowing waters. It is not known in which streams around Renuka Wetland Mahseer will spawn (a critical study must be undertaken as part of the adaptation plan), but increased rainfall may impact the breeding of the species as the shallow streams may become highly silted. It may also fill the stony riverbeds with silt, leading to the killing of eggs and fingerlings.

ADAPTATION MEASURES

De-silting of the Lake by dredging and manual removal of accumulated sediments and organic matter: De-silting of the lake will be undertaken by the Wetland Authority in close co-ordination with the Forest Department, Wildlife Department, and Mandir community. The cost of de-silting will need to be covered through a specific budget allocation. This measure should be thoroughly assessed for its environmental and ecological effects and only undertaken with expert supervision, given its potential to cause serious impacts on lake habitats and species. If the dredging process is successfully completed, it will go a long way in overcoming the impact of climate change on Mahseer populations.

Alternative fish feed from outside can be given to the fishes during this period by tourists but only after its standardisation and approval by the Fisheries Department: Providing external fish food for tourists is viable and cost-effective and can be started immediately. It will need to be standardised by the Fisheries Department to ensure that it provides appropriate nutrition. It will have a partial effect in removing the impacts of shortage of food and the adaptation measure will need to be undertaken until the food availability situation improves.

Breeding of Mahseer in a hatchery: Developments of breeding and culture techniques along with hatchery management practices as the means for conservation is desirable if it is shown through field survey that the population is declining. The activity will be undertaken by the Fisheries Department, but a special budget allocation will be needed due to the high cost in starting a hatchery[10]. The adaptation measure will have a partial effect in maintaining the Mahseer population, but it will last for a long time once the hatchery is operating effectively.

Other adaptation measures required to safeguard the Mahseer population relate to catchment rehabilitation and management. They have been described earlier in this chapter and include:

- Installation of silt trapping mechanisms before the silt reaches the lake through bags made of biodegradable geotextiles.
- Construction of drainage lines and diversions that carry runoff and sediment flows.

[10] Breeding of Mahseer in hatchery, developments of breeding and culture techniques along with hatchery management practices as the means for conservation", according to Debajit Sarma, M. S. Akhtar, Prakash Sharma and A. K. Singh. 2018. Resources, breeding, eco-tourism, conservation, policies and issues of Indian mahseer: A review, Journal of Coldwater Fisheries.

- Stream-bank erosion control measures.
- Improving the management of land and water through soil conservation measures.

5.4.2 Increase of temperature during SW monsoon

Temperature increases during the monsoon will alter the surface water temperature, which in turn may directly impact the breeding of the Mahseer as the species prefers to breed in colder waters.

ADAPTATION MEASURES

The measures required to address the impacts of increasing temperatures on the Mahseer have been described earlier and include:

- Increasing the area under local tree species having a high Leaf Area Index to make the lake and feeder streams cooler.
- Tree cover shading the banks of the lake to cool lake waters.
- Aeration of the lake to increase dissolved oxygen content.
- Improving the management of land and water through soil and water conservation measures.

5.4.3 Flood and Drought

As the intensity of rain has increased over the years and with it flash flooding, the very high additional load of silt is destroying Mahseer habitat and reducing the lake's size. Also, flash floods are impacting on fertilised eggs and shallow water habitat and feeding.

Drought conditions always negatively impact fish, leading to higher mortality, especially when combined with raised temperatures and lowered dissolved oxygen levels. They will alter or reduce the availability of natural food.

ADAPTATION MEASURES

Flood management measures, through improving and repairing existing damaged protective structures and introducing bio-engineering measures in the catchment. These include non-structural measures such as installation of flood warning and forecasting systems and structural protection measures in the catchment, including measures for flow retardation, flow deviation and acceleration of outflows from the lake through pipelines.

Infiltration and ground water recharge and increase in spring water output. Various measures are available to increase ground water levels during the monsoon, in preparedness for drought events that may follow. The catchment ground water recharge can be facilitated by tree planting or through bio-engineering measures depending upon the site in the catchment and need. Also, by evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant locations.

5.5 Turtles

Three freshwater turtle species are found in Renuka Lake, *Batagur kachuga, Nilssonia gangetica* and *N. harum.* The Red-Crowned Roofed Turtle is Critically Endangered, and is the males are characterised by bright colours such as red, yellow, white and blue on the face and neck. *Batagur* turtles are the most threatened freshwater turtles in India. The *Nilssonia* species – the Indian Softshell and the Indian Peacock Softshell are both Endangered. They feed on aquatic vegetation, macroinvertebrates and small fishes. All three have terrestrial nesting sites. Watching and feeding the turtles in Renuka Wetland is one of the tourist attractions.

5.5.1 Increase of rainfall during SW monsoon

With increased rainfall or increased intensity of rainfall, soil erosion will increase, leading to increased siltation and eutrophication and loss of turtle habitat. The food availability will also decrease with eutrophication and lower dissolved oxygen levels, impacting the population of turtles.

ADAPTATION MEASURES

Although turtles eat a wide variety of food from aquatic plants to fish, supplementary feed from outside, e.g., by tourists can be given during unfavourable conditions: Giving external food is viable and cost-effective but standardisation by the aquatic wildlife experts is required, accompanied by strict enforcement. Management of this activity will be conducted by the Fisheries Department and can be started immediately. It will reduce the impacts of food shortages at critical periods and sustain the population of turtles.

For religious reasons, the turtles of Renuka Wetland are protected from poaching and other external threats but as their habitat declines hatching and breeding at another location is necessary to preserve the gene pool and seed populations: The activity can be undertaken by the Wildlife Department and Wetland Authority in close association with a research organisation. Captive breeding will involve significant cost and involves some sort of research and development, so the budget needs to be allocated for it separately. It will not reduce these climate change threats but will provide a contingency plan.

Other adaptation measures to build resilience in the turtle populations to the more intense monsoon conditions and linked erosion have been described earlier in this chapter. They include:

- De-silting of the lake by dredging and manual removal of accumulated sediments and organic matter.
- Use of silt trapping mechanisms before the silt reaches the lake through biodegradable geotextile.
- Construction of drainage lines and diversions that carry runoff and reduce sediment flows into the lake.
- Stream-bank erosion control measures.

5.5.2 Decrease of rainfall during dry seasons

A decrease in underground spring discharge can have a double impact because the outer periphery is already filled up with silt, and with decreased rainfall, the low spring discharge may lead to quick drying out of the muddy banks for nesting.

ADAPTATION MEASURES

Increase in spring water output through rehabilitation of the catchment. The lake water is totally dependent on springs, and so to maintain the lake water levels, rainwater percolation and ground water recharge in the catchment are required. Measures for catchment rehabilitation and maintenance have been described in the section on these upstream assets.

Other measures that have been described include:

- Infiltration and ground water recharge
- Rejuvenation of springs via source and sink protection.
- De-siltation so that the periphery of the lake has a larger water-holding capacity.
- Increase in tree cover in the peripheral area.

5.5.3 Floods and droughts

Flash floods may wash away turtle habitats and areas suitable for nesting, reducing the number of nests and the population in the succeeding years.

During drought conditions, higher thermo-evaporation reduces the lake volume. A low recharge of catchment areas decreases the water output of internal springs. The reduced lake water level and quality mean that less food is available for turtles, reducing their populations.

ADAPTATION MEASURES

Nesting area protection, repair and restoration leading to increased availability of nesting habitat: This measure is feasible and cost-effective. It is to be implemented on an annual basis by the Wildlife Department. Also, the catchment-wide flood management measures described earlier are needed so that the nesting areas have some protection.

High thermo-evaporation can be reduced by injection of air bubbles into water. In summer the surface water heats and becomes less dense. Below this surface layer, which is 3 – 4 m deep, the water remains cold and dense. Artificial de-stratification will happen when a bubble plume is injected in the cold deep layer. Consequently, evaporation is reduced by balancing temperature gradients over the depth of the storage (Yara et al., 2019). High thermo-evaporation can also be reduced by floating plants and establishing treed wind breaks.

Other important measures to reduce the effects of drought conditions on turtles have been considered earlier, including:

- Water conservation measures in the catchment.
- Increased tree cover for better ground water recharge.
- Supplementing food during unfavourable conditions.
- Hatching and breeding turtles in captivity.

5.6 Tourism

Renuka Wetland and its temples attract religious and nature-based tourism. The annual Renuka Fair is a big attraction. Other tourist attractions include the wildlife sanctuary, mini zoo, and boating on the lake.

5.6.1 Flooding and increased rainfall, temperature and humidity during SW monsoon

Increased rainfall during the monsoon will impact daily tourism and recreational activities negatively. The area will be less attractive due to high humidity and intensive rainfall. There may be decreased road access by flooding reducing road condition and an increased risk of landslides.

Flash floods trigger landslides and soil erosion, leading to road blockages. They increase the perceptions of risk in accessing Renuka Wetland for tourists, leading to reduced tourist numbers and impacting local livelihoods. Droughts can have negative impacts on the sector through water shortages, intensification of pollution problems, leading to reduced tourist numbers, which will impact the livelihoods of tourist operators.

ADAPTATION MEASURES

Three approaches are recommended for adaptation to increased rainfall during the monsoon: • improved road safety and early warnings, • promotion of different types of tourism to ensure visitor numbers do not reduce at this time and • improvement of the facilities for dealing with large visitor numbers at the site.

- ***Improved road safety and early warnings***

Increased focus on road safety measures and engineering/bioengineering measures to be undertaken to reduce risks at vulnerable points: The risk of landslides is a major concern in hilly terrains and often associated with disasters. Bioengineering can be used to increase road slope stability through mechanical reinforcement, controlling erosion, increasing the infiltration ratio, reducing runoff and moderating the soil moisture. Techniques that are suitable for a particular area should be selected on the basis of availability of resources, site condition and required function. Following heavy localised rainfall, high levels of runoff can cause a flash flood even from small catchments and degradation and blocking of roads. Bioengineering measures slow and trap runoff and reduce the rate of outflow. Appropriate techniques include palisades, vegetated drainage lines, brush layering, and bamboo and wattle fencing with live pegs, supplemented by geotextiles.

This activity will need to be undertaken by the government agency responsible for roads, i.e., the Public Works Department (PWD). It will be an ongoing activity requiring regular maintenance, additional budget support and specialist expertise.

Weather-based early warning updates: Early warning systems can be used to reduce the risk to tourists and tour operators. The activity will be undertaken by the Meteorological Department in co-ordination with the Tourism Department.

- ***Promotion of different types of tourism***

Expanding scientific research-based sustainable tourism by engaging various universities and research institutes to send researchers to conduct surveys and studies during the monsoon when most universities are closed for summer vacations. This activity will be promoted by the Tourism Department in association with the Forest Department and require a promotional budget as well as regular liaison with institutes and research-based organisations. To date very limited research has been undertaken on critical conservation issues and species in Renuka Wetland - a gap which greatly inhibits good management.

Other activities to be conducted by the Tourism and Forest departments include:

- Development and promotion of eco-tourism sites around Renuka Wetland for nature enthusiasts and wilderness seekers.
- Increased activities to promote Renuka as a destination for nature trails and wildlife-based tourism, such as camps and tour packages during the tourist season.

- ***Improvement of tourist facilities***

To succeed in each of those activities, the facilities around Renuka Wetland will need to be significantly upgraded and managed in an environmentally sensitive way. The tourist facilities are inadequate to cope with existing visitor numbers. The natural areas around the lake are being encroached upon and degraded by tourism developments and activities. A lack of wastewater treatment and a lack of appropriate management of solid wastes and plastics are steadily diminishing the values that tourists come to experience.

Climate changes, such as increased rainfall in the monsoon, will aggravate the situation. Adaptation measures should include rationalisation and planning of the tourism facilities and accommodation, together with the improvement of wastewater treatment and solid waste disposal. These measures will have to be planned and implemented by the Sirmaur district, the temple and religious fair organisation and local tourist businesses in co-ordination with the Wetland Authority and the Forest Department.

Other measures are needed to build resilience in the tourism sector to floods and drought, including:

- **Flood insurance** will reduce the financial risk for individuals. Proper insurance can mitigate the impacts of extreme events. Floods can lead to high losses to tourism businesses. Appropriate insurance is needed and should be promoted by the Tourism Department in conjunction with insurance agencies and various community stakeholders.
- **Non-traditional insurance products,** such as parametric insurance, can also be explored with a mechanism for the payout for wetland ecosystem rehabilitation, triggered by an extreme event.
- **Diversifying the local businesses** that are focused on tourism and recreation activities outside the sensitive Renuka Wildlife Sanctuary.
- **Promotion of dry weather activities** like rock climbing, trekking and cultural tourism, which require dry weather for a pleasurable outdoor experience.

The Tourism Department, in collaboration with a government-based skill development agency, can promote other tourism activities outside the sensitive core area of Renuka Wetland. This will reduce the stress around Renuka Wetland and the immediate catchment. New infrastructures will be required for tourist accommodation outside the core area. The religious and recreational visitors are currently confined to the lake area and without adequate facilities are causing contamination of the site, especially during the fair and when tourist numbers are very high.

6 GUIDANCE FOR SITE MANAGERS

The adaptation measures that need to be undertaken at the Renuka Wetland have been organised and planned on the basis of need and timeframe - immediate (within the next year), short-term (over the next 2 years) and long-term (over the next 10 years).

6.1 Components of the adaptation plan

6.1.1 Ensuring freshwater flows to the wetland

Some immediate and short-term adaptation options, as shown in Table 9, are suggested for implementation to ensure freshwater flows to the wetland.

Table 9 *Adaptation measures for ensuring freshwater flows to the wetland*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Obstructing the natural flow of water entering into the lake for silt control and increased ground water recharge			
Construction of siltation and settling pools in the catchment			
Terracing in the slope areas where maximum runoff happens			

6.1.2 Catchment management

Adaptation measures for catchment management are described in Table 10.

Table 10 *Adaptation options for catchment management*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Increased gap-filling Afforestation in the catchment areas			
Bio-engineering methods for erosion control			
Drainage line which carries runoff and sediment flow			
Stream Bank Stabilisation measures			
Increasing the local species having a high LAI to make forests cooler			
Increase tree species diversity – Investing in species that are local and more resilient to change			
Pre-treatment of seedlings			
Genetic engineering of trees			

6.2 On-site management measures

Table 11 sets out adaptation measures that are recommended for inclusion in the site management plan.

Table 11 *On-site management measures*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Increased gap-filling afforestation in the catchment areas			
Bio-engineering methods for erosion control			
Drainage line which carries runoff and sediment flow			
Stream Bank Stabilisation measures			
Increasing the local species having a high LAI to make forests cooler			
Increase tree species diversity Investing in species that are local and more resilient to change			
De-siltation of the lake			
Balance of shallow water habitat for migratory & dry bank areas			
Tree cover shading the banks			
High thermo-evaporation can be reduced by injection of air bubbles			
High thermo-evaporation can also be reduced by biological covers (Floating Plants)			
Reduction in thermo-evaporation losses by windbreakers			
Afforestation along the flood channels around the lake area leads to retention of rainwater and reduces the discharge			
External feeding during extreme times			
Application of phosphorous-binding products to ward-off algal blooms			

6.2.1 Habitat restoration and management

The measures in Table 12 should be implemented for habitat restoration and management.

Table 12 *Measures for habitat restoration and management*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
De-siltation of the lake			
Balance of shallow water habitat for migratory & dry bank areas			

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
During dry season sprinklers can be used to keep the nesting area moist.			
Tree cover shading the banks			
High thermo-evaporation can be reduced by injection of air bubbles			
High thermo-evaporation can also be reduced by biological covers (Floating Plants)			
Reduction in thermo-evaporation losses by windbreakers			
Afforestation along the flood channels around the lake area leads to retention of rainwater and reduces the discharge			
External feeding during extreme times			
Application of phosphorous-binding products			

6.2.2 Species support and management

Adaptation measures in Table 13 are for species support and management.

Table 13 *Adaptation measures for species support and management*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
The increased silt can be tackled by soil and water conservation activities			
Increased aeration to increase dissolved oxygen			
Increasing water holding capacity of the lake			
Tree cover shading the banks of the lake can have a cooling impact			
Increase in tree cover in the peripheral area			
Alternative feed from outside			
Breeding in hatchery			
External feeding during extreme Events			

6.2.3 Livelihoods support and management

Lists adaptation measures for livelihoods support and management.

Table 14 *Adaptation measures for livelihood support and management*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Encouraging research-based tourism			
Promotion as a destination for nature trail & Wildlife based tourism			
Diversifying the local businesses that are focused on tourism and recreation activities			
Development & Promotion of alternative Eco-tourism sites outside of Renuka area			
Zoning and improvement of tourism facilities near Renuka Lake			
Improving wastewater treatment and solid waste disposal from tourism facilities			

6.2.4 Protection against extreme events

Adaptation measures for protection against extreme events are listed in Table 15.

Table 15 *Adaptation measures for protection against extreme events*

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Flood			
Improving & repairing existing damaged protective structures against flooding,			
Flow retardation: reservoirs (detention/retention basins)			
Flow deviation: construction of deviation channel			
Acceleration of outflow: through pipelines			
Flood warning and forecasting systems			
Afforestation along the flood channels which led to the retention of rainwater and reduce the discharge			
Streambank stabilisation measures			
Afforestation along the flood channels which led to the retention of rainwater and reduce the discharge			
Increase in silt trapping mechanisms before it reaches the lake through bags made of biodegradable geotextile			
Early warning and forecasting systems			
Insurance			
Flood management measures for nesting area for turtles			

Adaptation Measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Drought			
Soil conservation measures			
Plantation of local drought-resistant palatable varieties			
Social forestry			
New plantations selection based on future climate change projections			
External feeding during the time of drought for aquatic habitat			
Hatching and breeding under captivity as a backup measure			
Fire			
landscape flammability can be reduced through species selection			
Plan fuel breaks			
Setting up of forest fire monitoring & early monitoring system in areas known for a recurrent forest fire.			
Maximising the local broad leaf deciduous palatable species in the forest			
Setting up of multi-aged tree stands that are drought and fire-tolerant in existing stands			

6.3 Surveys, research and monitoring

6.3.1 Surveys

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

6.3.2 Research

There is very little scientific information available on the Renuka Wetland ecology and environment. There is huge scope for research on the wetland. A comprehensive research programme should lay down the important preliminary groundwork for a collaborative interagency programme to address the shortfalls in the current understanding of Renuka wetland ecology and its management, beginning with a better understanding of the characteristics and needs of the endangered and threatened species and their habitats.

6.3.3 Monitoring

A comprehensive monitoring programme is urgently required on Renuka Wetland and its catchment. Without it, all the trends are indicating that the wetland will be fundamentally transformed in the decades to come, with loss of biodiversity and its

scientific, cultural, touristic and livelihood values. Consistent, thorough and timely wetland monitoring, and assessment programs are a critical tool for Ramsar Site manager to manage and protect the wetland resources better. An effective monitoring programme allows managers to establish a baseline for the wetland's extent, condition and functions; to detect changes; and to characterise trends over time.

Research, surveys and monitoring are fundamental to both the detailed design of adaptation measures and their effective implementation and the overall adaptive management of the Ramsar Site. Renuka Wetland and its natural resources have not been fully surveyed and researched, and so it is difficult to be definitive about the baseline conditions and trends against which to assess change. There is an immediate need to fill some of the information gaps about the site as a first step in climate change and adaptation monitoring.

The structure of the monitoring programme should include:

1. Long-term measurement of climate parameters, including local air temperatures, maxima and minima, rainfall, humidity and wind speed and direction, including measurement of extreme events.
2. Monitoring of catchment conditions, including forest cover and species composition, identifying gaps in forest cover, areas of increased risk of soil erosion, condition of springs and streams feeding into the lake, incidence of forest fires, and incidence of invasive species.
3. Monitoring of the habitat conditions within the lake, including:

- Water quality, with a focus on temperature, dissolved oxygen, suspended solids and turbidity and nutrients and phytoplankton dynamics
- Bed and bank conditions, assessing sediment build-up within the Lake, identifying areas most prone to sedimentation and where dredging and silt removal may be carried out, and areas where migratory birds roost and where turtles nest.
- Monitoring of the deeper water and aquatic grasses, condition, species mix, presence of invasive species.

4. Monitoring of keystone species populations, including migratory bird, turtle and fish populations, especially the Mahseer.

- It is necessary to confirm which species of turtle exists in the lake and the optimum conditions for the long-term survival and breeding of the species.
- Censuses of the migratory birds visiting the lake should be carried out each year.
- For the Mahseer, identification of the spawning areas, including the inflowing streams, and ensuring both access and suitable conditions in these spawning areas.
- For all wildlife species, research into the climatic thresholds of when food sources will become less available and when supplementary feeding may be required.
- Monitoring the impacts of tourism on the conditions of the Ramsar site, including encroachment, effluents, water pollution, solid waste disposal and disturbance of wildlife.
- 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.

The above programme of research, surveys and monitoring will allow a targeted design and adjustment of the adaptation measures, by identifying areas and habitats where the adaptation measure will be implemented and then keeping track of its effectiveness. Once put in place, monitoring can show if the impact of negative influences and changes is reduced, if keystone species populations are recovering and thriving, if habitats are healthy and if the water quality is good. Alternatively, monitoring will show if there is a continued decline in conditions or numbers. In that case, the adaptation measures may require adjustment or need to be supplemented by other approaches.

6.4 Institutional arrangements for management

There are multiple stakeholders controlling different parts of the wetland, which leads to conflicts between them in terms of mandates and inconsistent actions.

It is important to keep in mind that Renuka Wetland is recognised as a nature sanctuary under the Wildlife Protection Act. A sanctuary is an area that is of ecological, faunal, floral, geomorphological, natural or zoological significance, declared for the purpose of protecting, propagating or developing wildlife or its environment. Certain rights of people living inside a Sanctuary can be permitted. Also, the District Collector may, in consultation with the Chief Wildlife Warden, allow the continuation of any right of any person in or over any land within the limits of the Sanctuary. So here lies the dilemma for effective conservation management of the site – the designation as a sanctuary and a Ramsar Site of international importance still permits development and use to continue, which may be damaging and degrading to the site. And this is what is happening at Renuka Wetland.

Some of the main institutional stakeholders are shown in Table 16:

Table 16 *Main organisations and their responsibilities at Renuka Wetland*

Name of stakeholder/ group	Rights, roles and responsibilities of the Ramsar wetland site
Forest Department, Wildlife Wing	Management of nearby forest, eco-tourism, wildlife, monitoring and evaluation of flora and fauna.
Sirmaur District Collectorate under the Deputy Commissioner	Has overall authority but relatively little capacity for co-ordination and facilitating management and use of the site by relevant organisations.
Wetland authority	As the wetland falls under the sanctuary all the powers are with the Forest Department and the Wetland Department has no direct control over the wetland.
Forest Department Renuka wetland, Territorial Wing	Management of catchment, eco-tourism, monitoring and evaluation of flora and fauna in the catchment area.
Renuka Development Board	Conducts the annual fair, maintains boating in the wetland and is committed to increasing the number of hotels in the immediate vicinity of the lake as well as constructing other fair-related infrastructure (“The temple was there before the Ramsar Site”).
HP Tourism Hotel	Management of the guests and hotel.
Himachal Pradesh Tourism Development Corporation	Actively promotes Renuka Wetland as a tourism destination with multiple recreational opportunities, but with no responsibility to ensure effective management of tourism facilities or consideration of carrying capacity.
Sirmaur District Government	Actively promotes Renuka Wetland as a tourism destination.
Himachal Pradesh Public Works Department.	Construction, maintenance and repair of roads in the catchment and to access the site.

There is no permanent platform that brings relevant agencies together to ensure co-ordinated management of the site. At the district level, the Sirmaur District Collectorate has the overall authority, and under the Deputy Commissioner’s chairmanship, yearly or half-yearly meetings are held with all the stakeholders. In 2020, the District Collectorate convened a meeting that brought together the key agencies to come to a workable solution for the problems the site is facing. A number of decisions were made regarding the responsibilities of various stakeholders, but the key institutional conflicts of interest were not resolved.

Apart from these infrequent district-level meetings, the management authority and roles remain confused and uncertain. Various aspects of the work, roles and responsibilities are defined and involve collaborative arrangements – for example:

- The Renuka Development Board and local administration are responsible for conducting the annual religious fair.
- The Forest Department (its territorial wing) is responsible for carrying out catchment treatment
- The Wildlife Wing of the Forest Department is responsible for conservation of the sanctuary areas and the reserve forest.
- The State Wetland Authority is responsible for the conservation of Renuka Wetland, though due to lack of manpower they depend entirely on the Forest Department.

Hence, different aspects of Renuka wetland management are with different stakeholders and discussed in different platforms, which is not a situation conducive to systematic conservation of the wetland. The institutional complexity is compounded by uncertain and overlapping authorities and budgetary commitments – and a lack of a system of monitoring and evaluation that will disclose the problems and priorities for action more clearly. All the agencies are individually involved in planning for the activities pertaining to them without working to implement a united and integrated management plan for the Ramsar site.

The major issue that has arisen in an effort to involve all the stakeholders in planning is regarding the ownership of the site. All the stakeholders have put forth their rights to the site. Under the Act, the Wildlife Wing of Forest Department has responsibility for the wildlife sanctuary but being also a Ramsar Site of international importance, the State Wetland Authority feels that lake's authority should be with them.

The institutional tangle is further complicated as the Renuka Vikas Board has permission to operate and earn revenues from boats for tourists, but the Forest Department considers that this activity dilutes their management authority over the lake as envisaged by law. Another issue is the illegal encroachment of the forest land by ashrams who feel they have a genuine right as this is an ancient religious site - day by day more and more native forest area is being encroached by the ashrams with the full support of the Board. Yet, under the law, there can be no outside interference in a wildlife sanctuary. This issue has been prominently highlighted by the other stakeholders.

Most of these key institutional issues have reached the courts, but it seems no organisation is willing to lose its control or give up its interests. Mediation at a higher level is required to resolve the situation, which is leading to the steady degradation of the site. Unless one agency with appropriate capacities is given overall authority to manage the Ramsar Site while involving all stakeholders in planning, monitoring and implementation, effective conservation will not be possible.

6.5 Stakeholder engagement

The stakeholder analysis and consultations at various stages during the vulnerability assessment and adaptation planning process were conducted to gather views, advice and information from those most involved and affected by the Renuka Wetland site management.

6.5.1 Stakeholder views

The following recommendations were made by stakeholders during the consultations.
Given the global importance of its biodiversity and endangered species, consideration should be given to elevating the site from a sanctuary to a national park under the Wildlife Protection Act. The sanctuary designation does not bring the needed level of clarity on the objectives of the site and on authority for its management. The difference between a sanctuary and a national Park mainly lies in the vesting of rights of people living inside. Unlike a sanctuary, where certain rights can be allowed, in a national park, no rights are allowed. No grazing of livestock is permitted inside a national park, while in a sanctuary the Chief Wildlife Warden may regulate, control or prohibit it. In addition, while any removal or exploitation of wildlife or forest produce from a sanctuary requires the recommendation of the State Board for Wildlife, removal from a national park requires the recommendation of the National Board for Wildlife. Encroachment is not permitted. So, the National Board of Wildlife will have the authority to allow certain religious tourism activities and facilities to continue functioning inside the core area – but only under strict controls.

Land uses and zoning the catchment and wetland should be defined with zones linked to overriding safeguards which determine the development activity which can proceed.

Remote sensing of lake eutrophication and silt deposition will be an important component of the monitoring programme to supplement field-based survey so that the rate of eutrophication and siltation can be ascertained, and the management plan prepared.

The Forest Department proposed that during the lean period tourism should not be promoted and rather it should be banned so that the ecologically sensitive area has an opportunity to recover and that the period should be dedicated for conservation activities only. Further the Forest Department proposed that boating on the lake, which is adding pollutants and disturbance, should be tightly controlled. The Tourism Department has allowed boating in the lake and earns revenue from it. A part of that revenue should be spent on conserving the wetland.

Carrying out a bird censuses is essential to ascertain the migratory and local bird species, their numbers and their habitat requirements so that a proper conservation plan can be prepared and implemented for the conservation of migratory and local bird habitats.

Many activities for conservation of the wetland either are delayed or remain pending because annual activity budgets get approved late or after the appropriate seasons for undertaking such activity has passed and by the time the new season comes, the annual budget has lapsed. Also, there are many budgetary constraints – the required budget for an essential task is not available or the budget available is too small for carrying out activities. Additional funding sources need to be tapped. The budget that is needed for undertaking adaptation activities need to be estimated and sources and responsibilities determined.

Various organisations are undertaking surveys, monitoring and research at Renuka Wetland but with little co-ordination or integration. It is important that the catchment, habitats and species be monitored systematically to keep in view their interdependence for the better management of the wetland. It is proposed that research and monitoring be overseen by a common management committee headed by the State Wetland Authority, with the SWA taking overall responsibility for managing the research programme.

7 CONCLUSION

This report provides an assessment of the vulnerabilities of Renuka Wetland 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 a general increase in the temperature throughout the year. The assessments show that these changes in seasonal climates will be exacerbated by an increased frequency and intensity of extreme events of flooding, droughts and forest fires.

The impacts of these climate changes will enhance current negative trends in the condition of the Renuka Wetland and its surrounding catchment, leading to further degradation of the site and, possibly, its complete transformation from a lake to a marsh unless appropriate actions are taken. One key issue is the increased siltation caused by runoff and soil erosion from the catchment. The lake has been filling with sediment, becoming shallower, changing the conditions of the shallow water habitats, aquatic grasses and banks where the migratory birds rest and feed and where the turtles nest. Sediments also coat the spawning sites of fishes such as the Mahseer.

A second key issue that will be exacerbated by climate change is the water quality of the lake, which already shows signs of eutrophication. Nutrients may be brought into the Lake from the sediments washed in from the catchment, which are likely to increase with climate change, but also from the wastewater and solid wastes reaching the lake from the tourism and religious establishments. Increasing temperatures are likely to enhance the eutrophication process, leading to algal blooms, which may include toxic cyanobacteria.

Tourism pressures on the wetland are also shown through encroachment on the forest areas surrounding the lake. The catchment is already very small, and further degradation of the forested areas will lead to increased soil erosion and runoff. The lake is dependent on the ground water and springs to maintain the water levels and flows during the dry season. A more rapid runoff because of deforesting and building up of the catchment will lead to increases in flooding in the monsoon and droughts during the hot seasons because the ground water recharge has been impaired.

A range of adaptation measures have been presented as options for dealing with these issues, some of which have already been included in the current management plan. This climate change assessment serves to reinforce the need for those management measures to be carried out with due care and attention, e.g., reforestation and gap filling in the catchment, and de-silting the lake, and budgets will need to be reviewed and allocated appropriately to be implemented. There are other adaptation measures that will also need to be planned and implemented in order to ensure the resilience of the lake and its surroundings to climate change. The feasibility and planning of these proposed adaptation measures will require appropriate survey, research and design, followed by ongoing monitoring to ensure effectiveness.

Implementation of all or some of these measures will need the co-ordination and co-operation of the different stakeholders

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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 is 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 power point presentations which describe the four case studies and the CAM methodology as training and awareness raising materials.

9.1.1 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

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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 involve six main steps as shown in Figure 19.

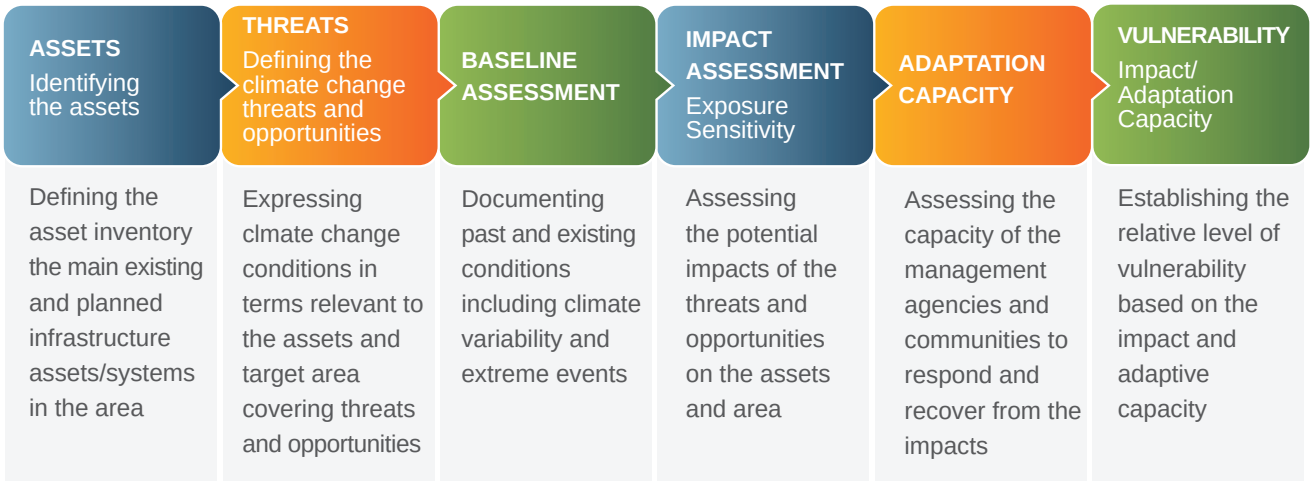


Figure 19 *Climate change impact and vulnerability assessment steps*

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 (Figure 20 to Figure 23).

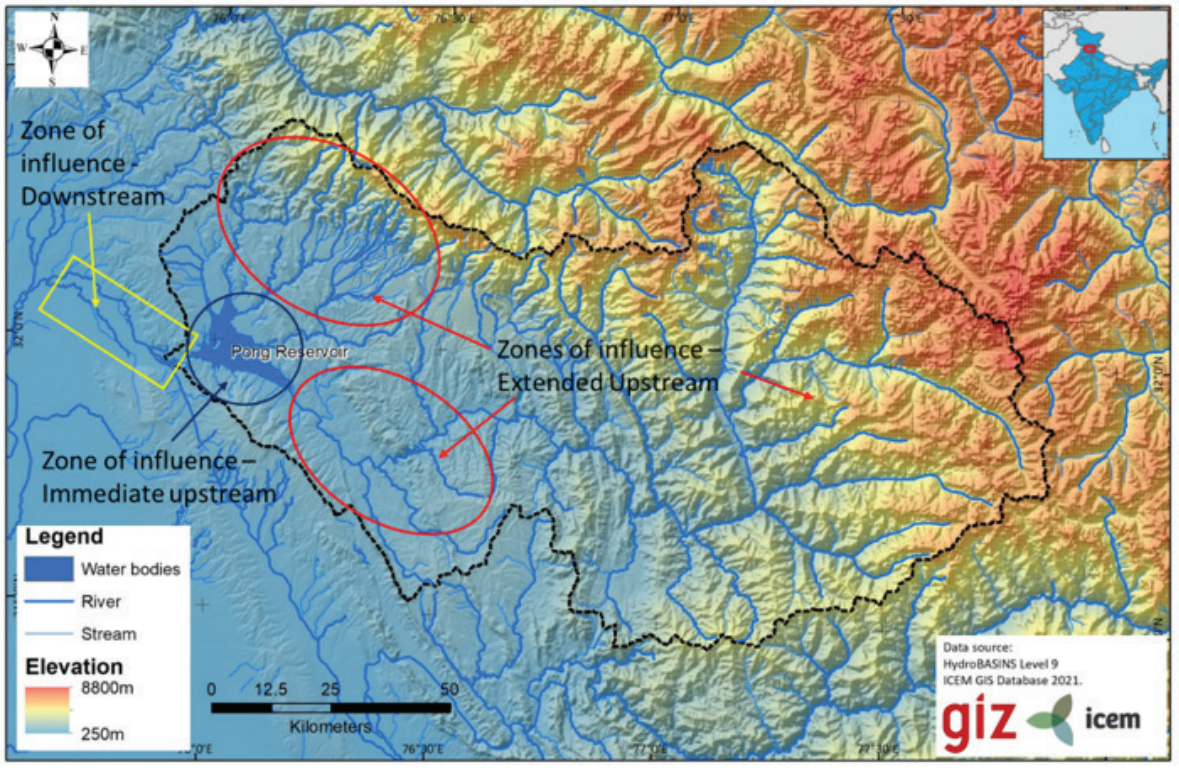


Figure 20 *Pong Dam Lake and zones of influence within its catchment*

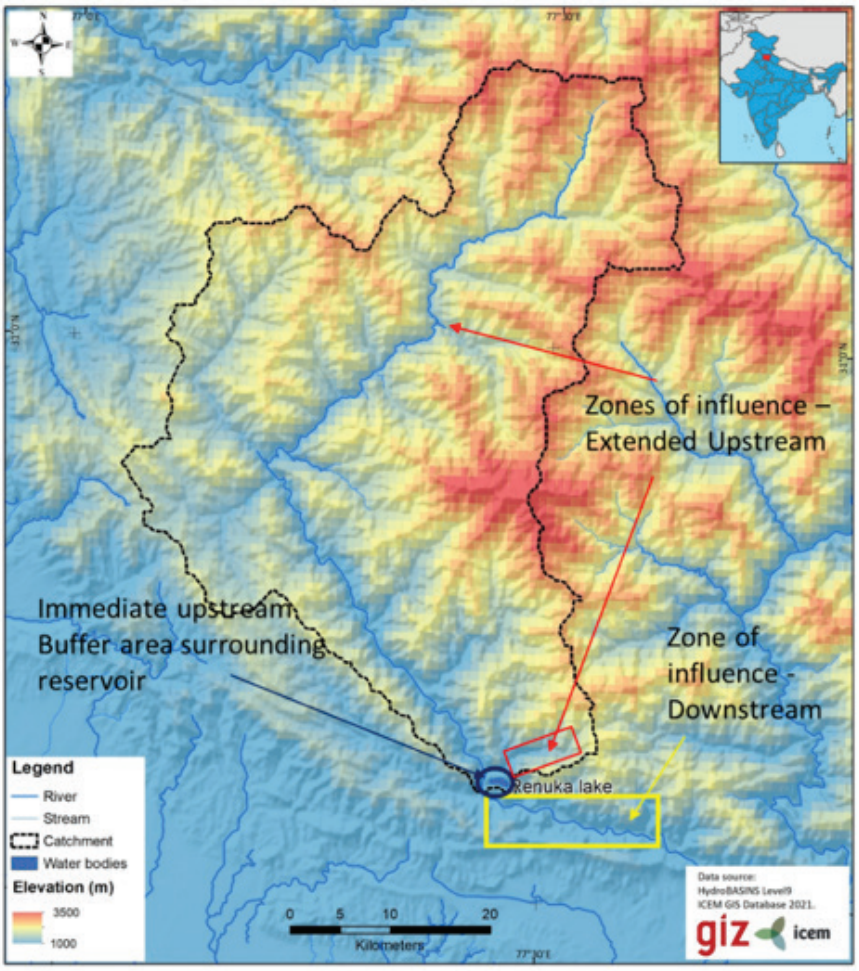


Figure 21 *Renuka lake and zones of influence within its catchment*

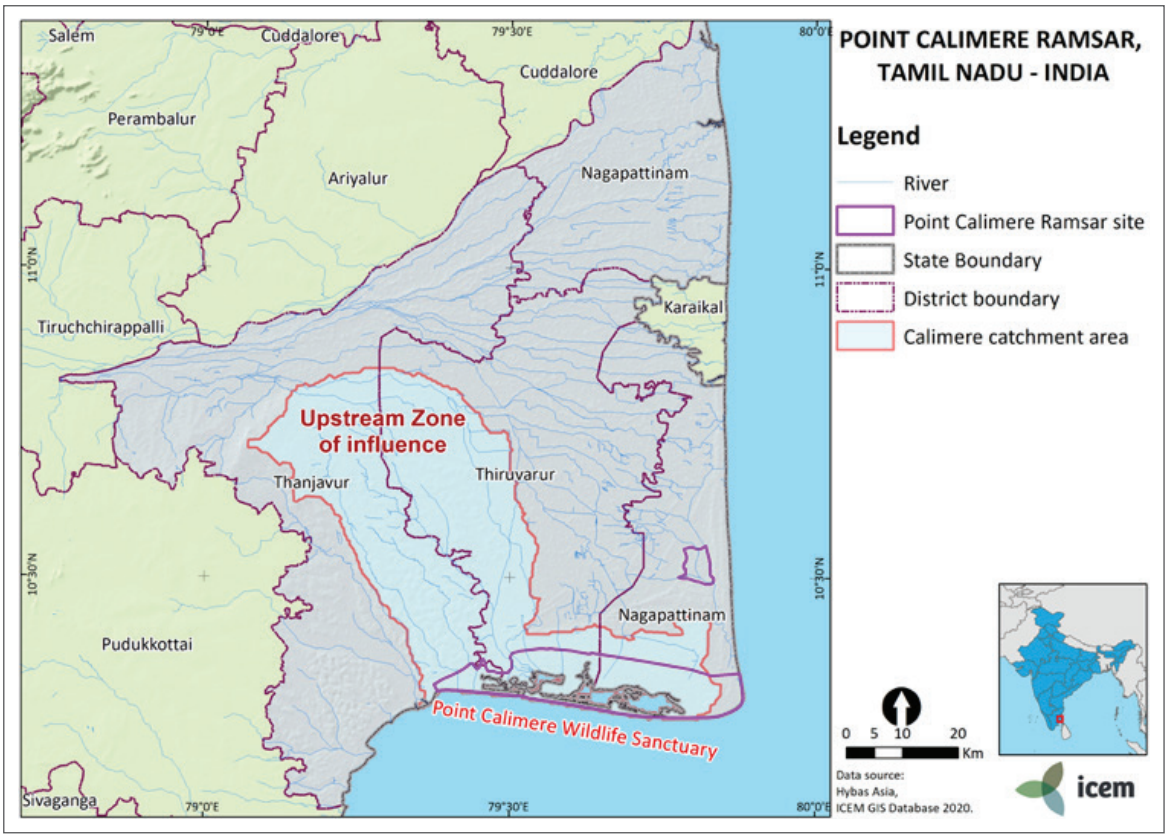


Figure 22 *Point Calimere Ramsar site and its upstream zone of influence*

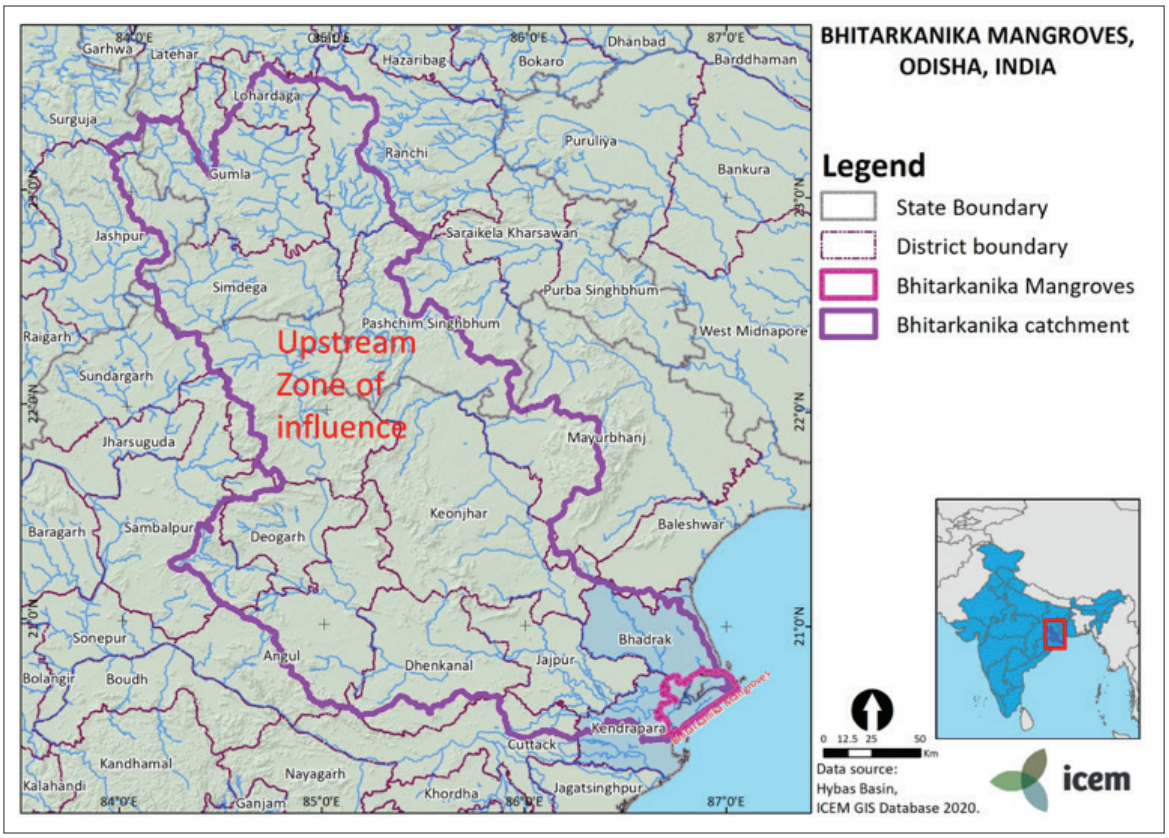


Figure 23 *Bhitarkanika Mangroves site and its upstream zone of influence*

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 will 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 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 Wetland - 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 will 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 17).

Table 17 *Scoring sheet to aid target asset selection*

Criterion	Question
Representativeness	To what extent is the habitat, species or ecosysytem service representative of the site?
Ecological significance	To what extent is the habitat, species or ecosysytem service significant for ecological pocesses?
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?
Sensitivity to change	To what extent is the habitat area/condition, species numbers or productivity of ecosystem service varied over the past 20 years as conditions change?
Non-climatic threats	To what extent is the asset threatened by non-climatic 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 24):

- 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 24 *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 (Section 3) 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
- 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 25).

Figure 25 *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 (Figure 20 to Figure 23).

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[11,12,13,14]
- National assessments in 2020 by the Ministry of Earth Sciences (MoES)[15], and in 2010 by the Indian Network on Climate Change Assessment (INCCA)[16].

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 Dam Lake that used the Co-ordinated Regional Climate Downscaling Experiment South Asia (CORDEX – SA) with RCP 4.5 and RCP 8.5 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^{o}C) across the Pong Dam lake 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^{o}C) for the baseline as well as future projections, that are important to the vulnerability assessment process.

[11] 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.
[12] ACWADAM and PSI, 2020. Renuka Wetland Hydrogeological Assessment, Management Strategies and Capacity Building. Interim Report. Prepared for GIZ.
[13] Institute of Technology and Sciences, 2020. Hydro-ecological assessment for integrated management of Point Calimere Ramsar site. Interim Report. Prepared for GIZ.
[14] Chilika Development Authority, 2020. Hydro-ecological assessment for integrated management of Bhitarkanika Ramsar site, Odisha. Interim Report. Prepared for GIZ.
[15] 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.
[16] 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.

Such detailed assessment has not been available for the other Ramsar Sites. Provided hydrological reports for Renuka Wetland, Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary 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 Lake were based on an ensemble mean of three regional climate models including REMO, RCA4 and CCAM. Whereas projections at Bhitarkanika Mangroves, 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).

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 will not be suitable for specific site-based assessment.

ICEM's site-based assessment method

Currently available assessments (i.e., from hydrological reports and national assessments) provide valuable references for this project but they are insufficient for site-based assessments. Using different data sources for each site will 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 2). The RCP 8.5 is characterised by increasing greenhouse gas emissions over time and represents scenarios in the literature leading to high greenhouse gas concentration levels. This high-forcing scenario shows significant changes in the climate system, which identify the contribution of human-caused warming to climate impacts, as compared 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).

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

Box 2 *About WorldClim data and RCP 8.5*

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 Dam Lake 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 26 and 27). 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 3.

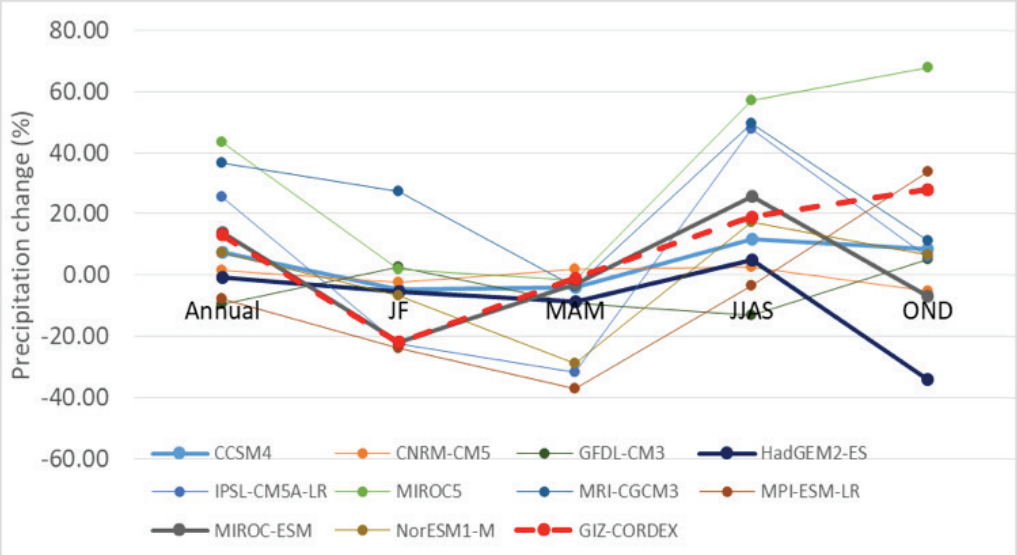


Figure 26 *Changes in precipitation in Pong Dam Lake Basin by 2050s derived from the 10 GCMs in comparison with results reported CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

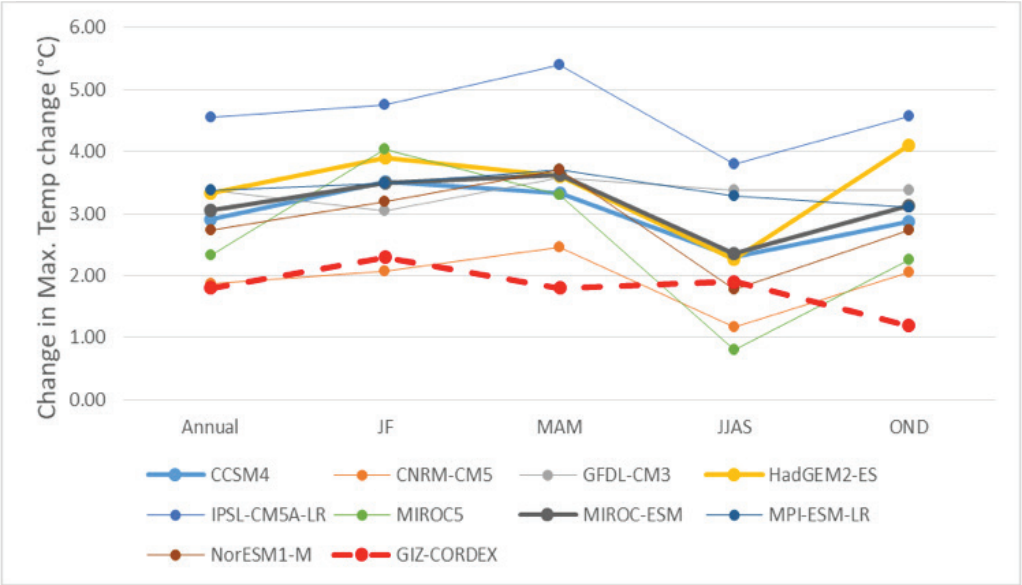


Figure 27 *Changes in temperature in Pong Dam Lake Basin by 2050s derived from the 10 GCMs in comparison with results reported CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

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 CO_2 emissions and simulate CO_2 concentrations. HadGEM2-ES has a high climate sensitivity of approximately 4.6°C for a doubling of CO_2 that places it near the top of the range (2.1°–4.7°C) of the CMIP5 models. An interactive tropospheric chemistry scheme is also included, which simulates the evolution of atmospheric composition and interactions with atmospheric aerosols. Taking into account climate change projections from models with higher sensitivity could lower the chance of a planned adaptation turning out to be inadequate, assuming that the range of model sensitivity is satisfactorily captured. Further information for HadGEM2-ES can be found in Martin et al. 2011 (https://gmd.copernicus.org/articles/4/723/2011/gmd-4-723-2011.pdf).

The Model for Interdisciplinary Research on Climate – Earth System Model (MIROC-ESM), is based on a global climate model MIROC which has been co-operatively 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 3 *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). 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 fertilisers which eventually is transported to delta regions through land runoff and river discharge, which are significant in Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary.

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 28 shows the parameters and issues that were considered in carrying out the impact and vulnerability assessment at the four Ramsar Sites.

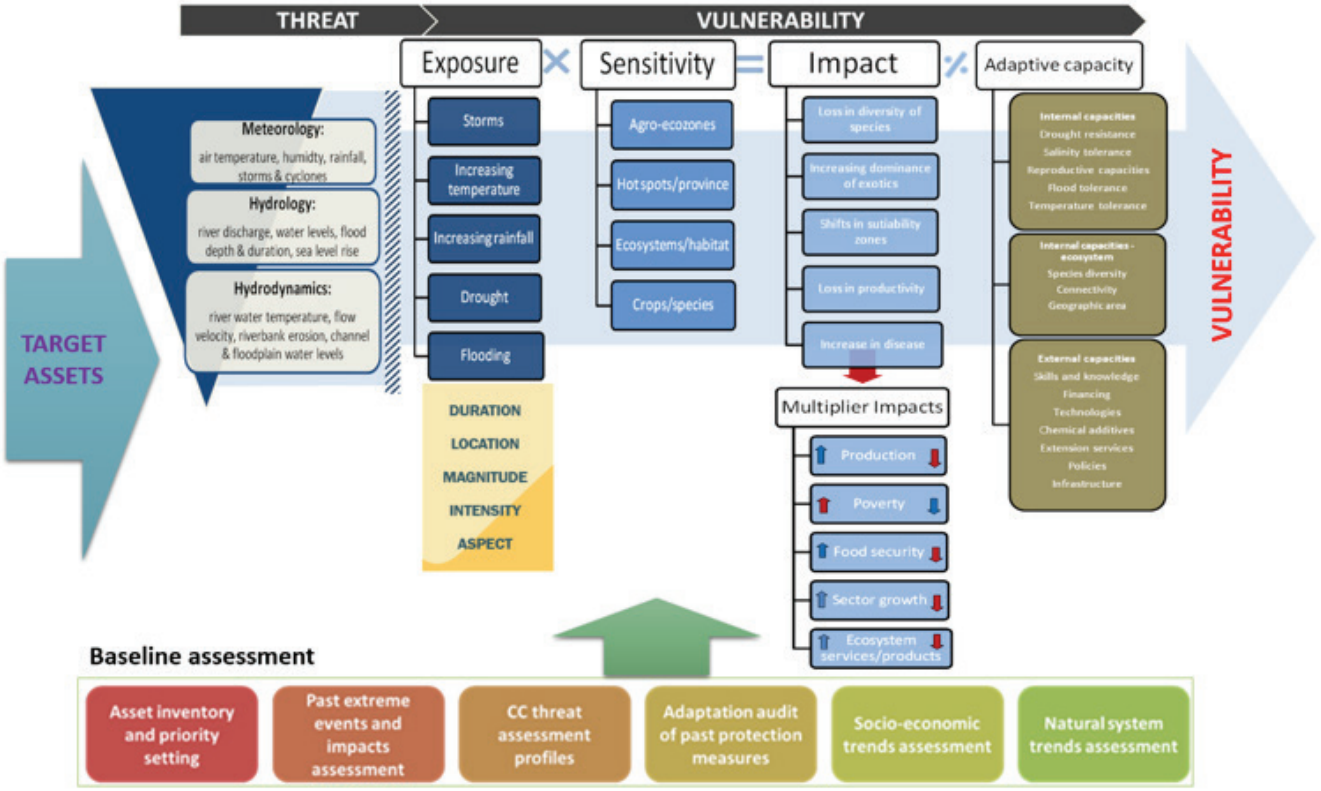


Figure 28 *Illustration of parameters and issues considered in the CAM baseline and vulnerability assessment process*

Exposure

The rating system for exposure and other parameters used scoring from very low to very high and was applied based on expert judgement drawing from the best available scientific and factual evidence and where appropriate community knowledge and experience (Figure 29).

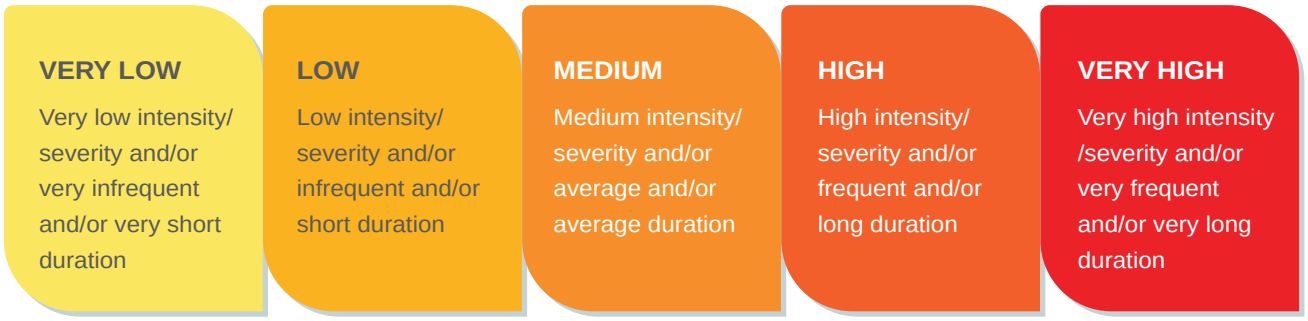


Figure 29 *Exposure scoring protocol*

Sensitivity

The next step in impact assessment was to rate the sensitivity which is the degree to which the exposure to a threat will negatively affect the integrity or operation of the system/asset. Taking into account those variables, the assessment team rated system sensitivity from very low to very high (Figure 30).

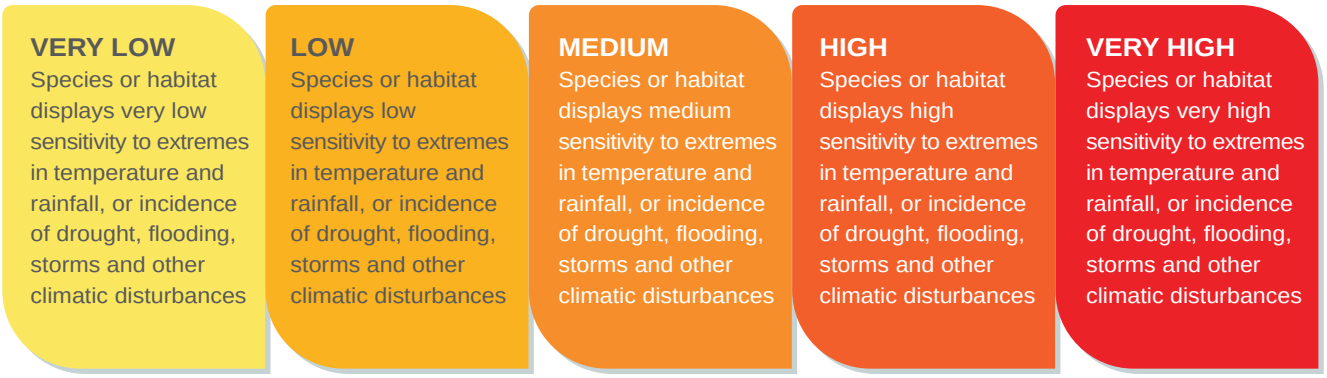


Figure 30 *Sensitivity scoring protocol*

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 will 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 will 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 18. 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 19.

Table 18 *Vulnerability Assessment Matrix for recording and annotating exposure, sensitivity and impact scoring*

Threat Category	Details of threats	Impact Assessment				Adaptive Capacity\	Vunerability (impact x adaptive capacity)
		Exposure	Sensitivity	Impact Level (exposure x sensitivity)	Impact Summary		
Seasonal Changes							
Temperature Increase							
Rainfall							
Extreme event changes							
Coastal flood events							

Threat Category	Details of threats	Impact Assessment				Adaptive Capacity\	Vunerability (impact x adaptive capacity)
		Exposure	Sensitivity	Impact Level (exposure x sensitivity)	Impact Summary		
Extreme event changes							
Upper catchment flash flood							
Storm surge							
Large scale extreme level flooding							
Sea level rise							

Table 19 *Determining impact score from sensitivity and exposure*

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

The impacts of climate change on each site and its target assets were described in the Vulnerability Assessment Matrix (Table 18). 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
- **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 31. The scoring system for adaptive capacity for external capacities is shown in Figure 32.

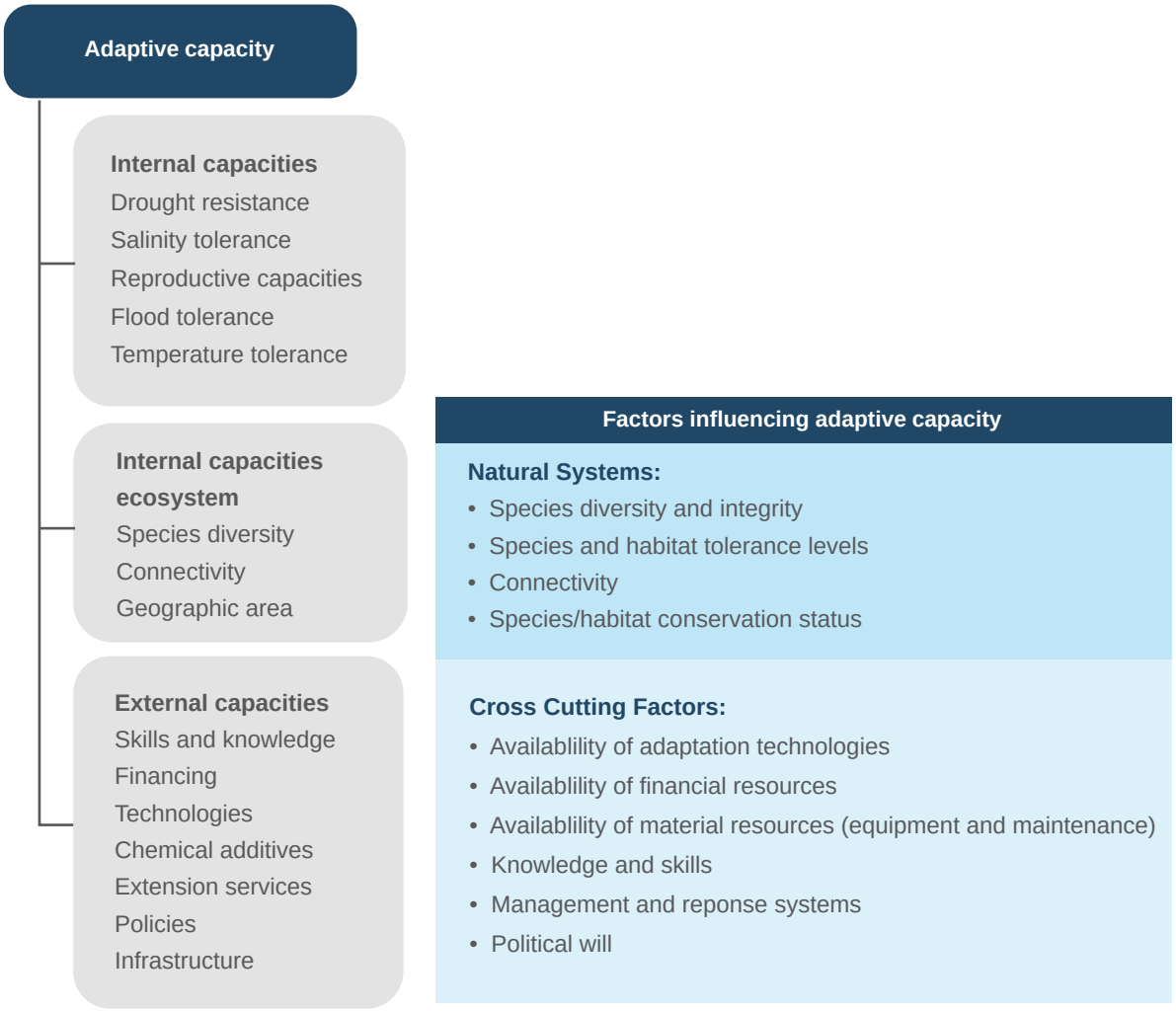


Figure 31 *Adaptive capacities and influencing factors*

Figure 32 *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 will 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 20.

Table 20 *Determining the vulnerability score from Impact and Adaptive capacity*

		Impact				
Adaptive capacity		**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 or financial resources	Low	Medium	Medium	High	Very High
	High Sound institutional capacity and good access to technical or financial resources	Low	Low	Medium	Medium	High
	Very High Exceptional institutional capacity and abundant access to technical or financial resources	Very Low	Low	Low	Medium	High

9.1.7 Key concepts in the climate change vulnerability assessment

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

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 21.

Table 21 *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 , 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, with climate change increasing the frequency (number of days) with increased maximum temperature, which could be indicative of the duration of heatwaves.

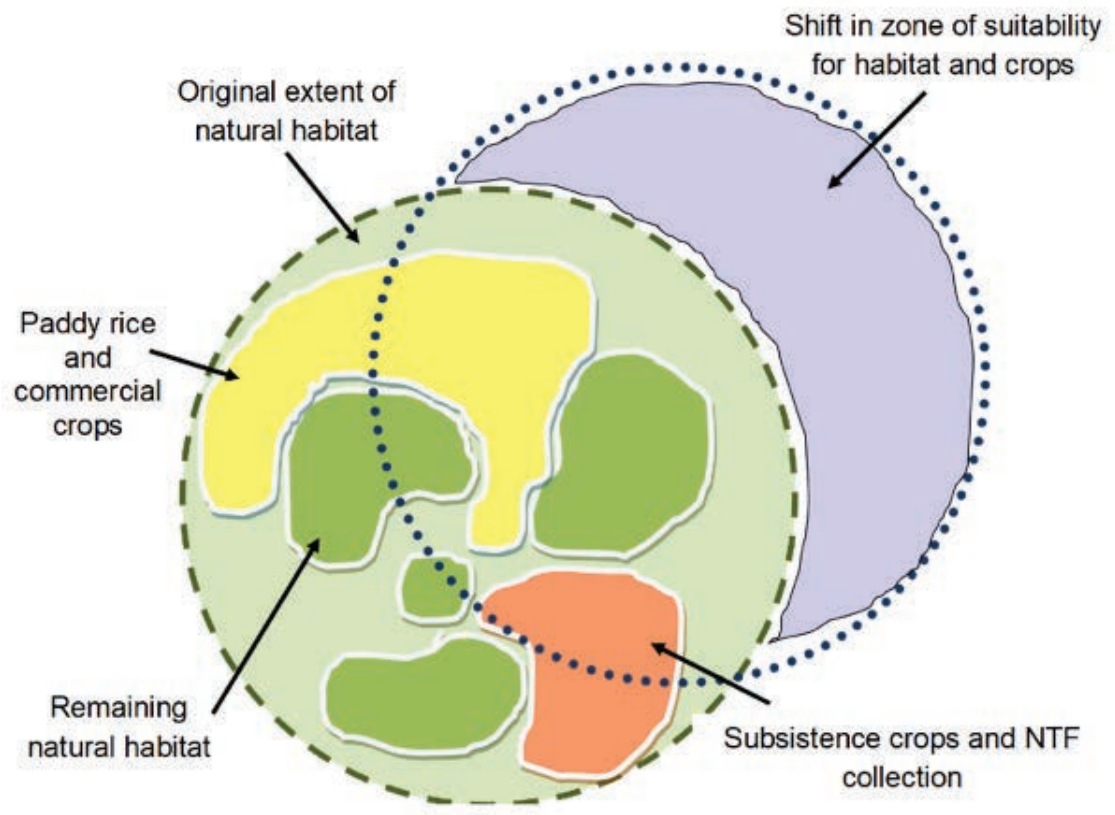


Figure 33 *Illustration of a geographic shift in suitability for habitat*

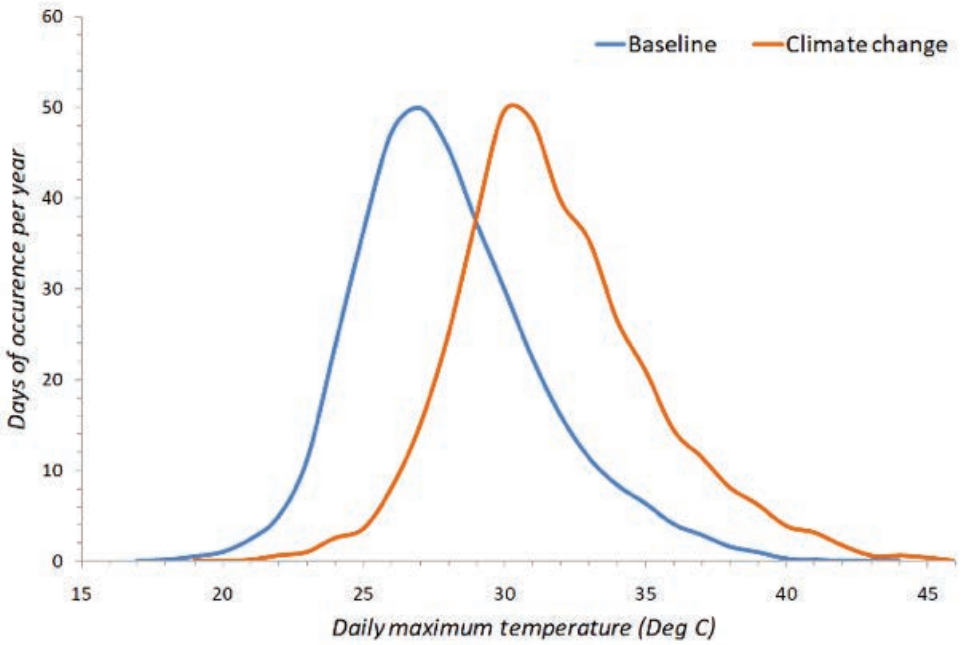


Figure 34 *Temporal shift increasing number of days with increased maximum temperature*

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 , 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.

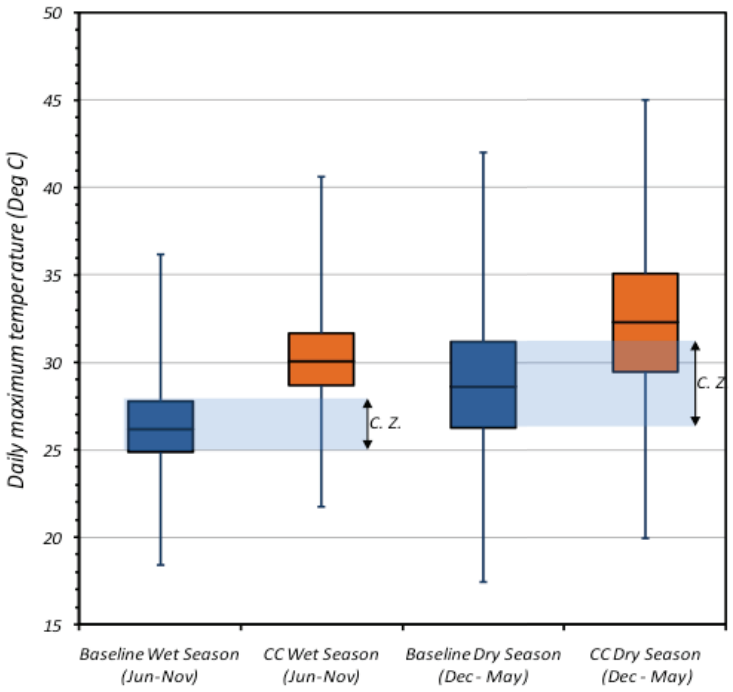


Figure 35 *Illustrating comfort zones: Daily maximum temperatures in the wet and dry seasons*

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[17], CABI Forest Science database[18], FishBase[19], the Reptile database[20], the IUCN Red list data[21], and the India Biodiversity database[22] 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 with 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 36 and Figure 37 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.

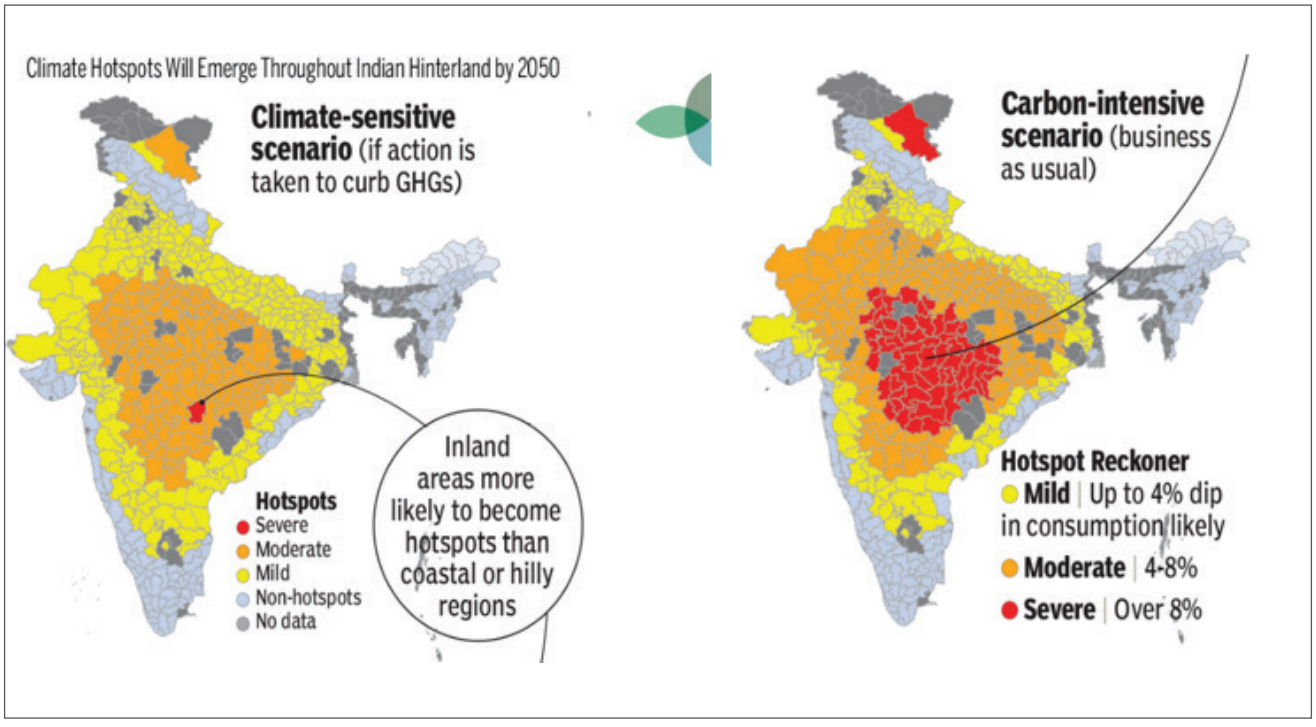


Figure 36 *Examples of India-wide temperature defined hotspots under two climate change scenarios (Source: Mani et al. 2018)*

[17] http://ecocrop.fao.org/ecocrop/srv/en/home
[18] https://www.cabi.org/forestscience/forest-trees/
[19] https://www.fishbase.de/
[20] https://reptile-database.reptarium.cz/
[21] www.iucnredlist.org
[22] https://indiabiodiversity.org/

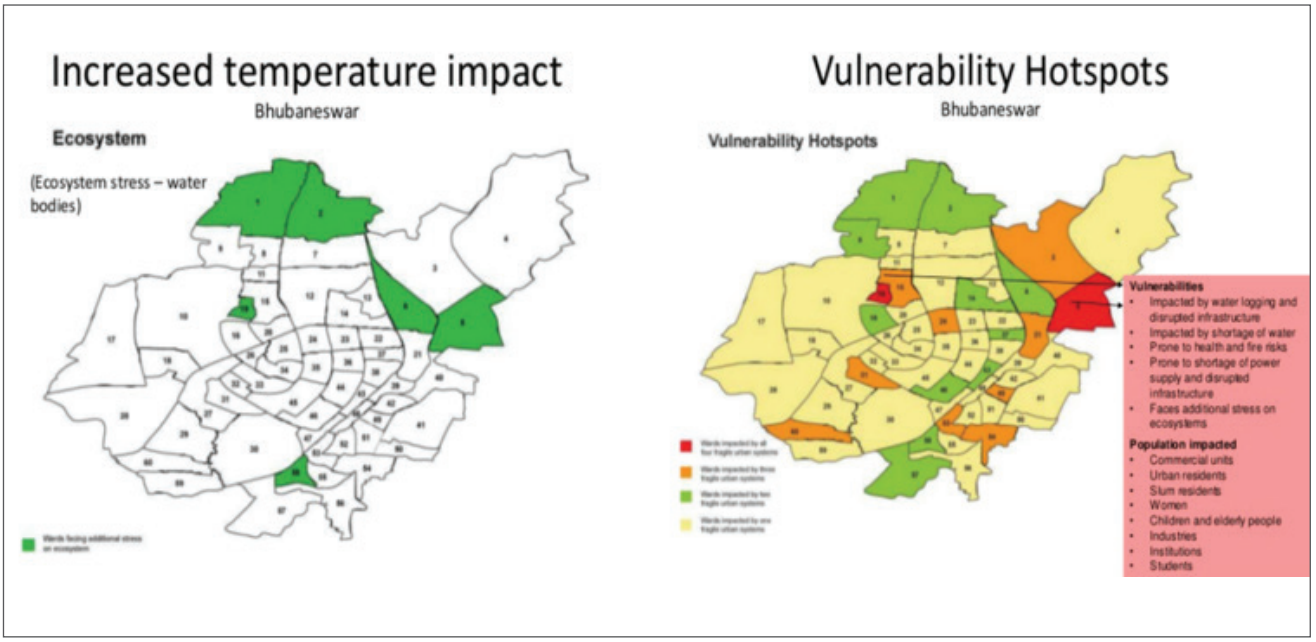


Figure 37 *Example for developing vulnerability hotspots from maps of increased temperature impact (Source: Dr W G Prasanna Khumar, Centre for Climate & Disaster Management, https://www.slideshare.net/wgpkumar/climate-change-and-india)*

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 38 shows the zones for soil moisture content in Odisha on a particular date.

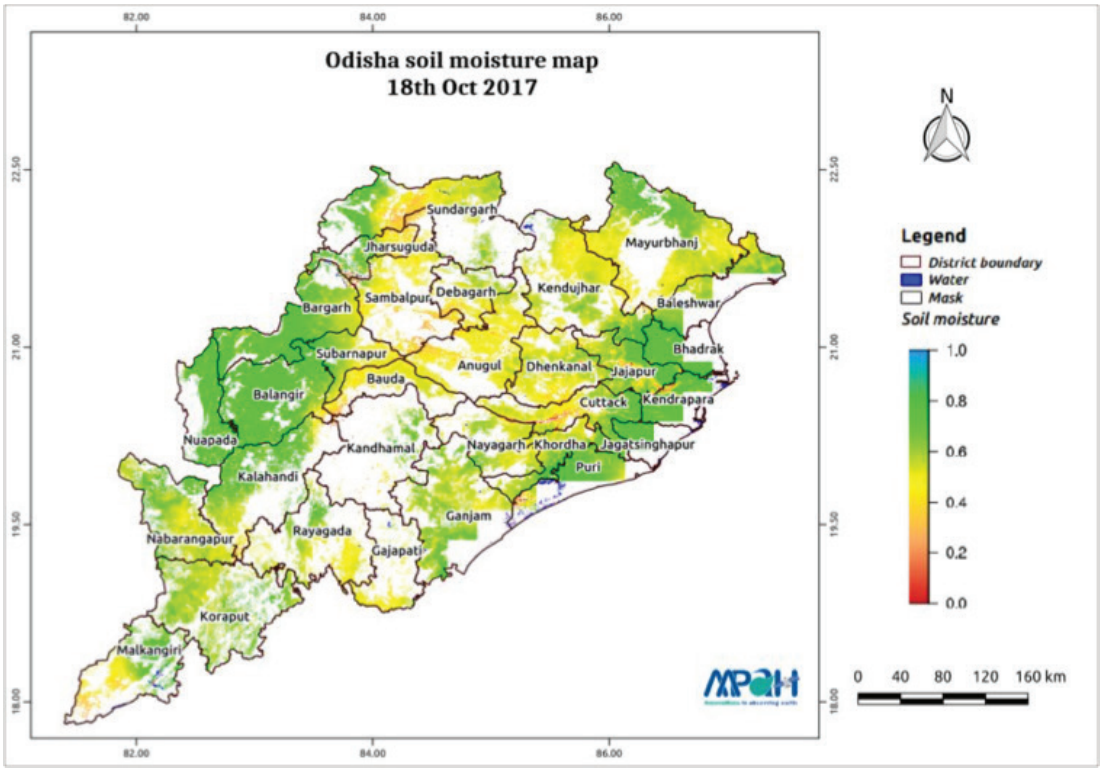


Figure 38 *Odisha soil moisture zonal map (Source: Aapah Innovations, http://www.aapahinnovations.com/soil-moisture-map-state-odisha-2/)*

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[23] (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 Dam Lake Basin (Figure 39). These variables are used in overlays to assess the potential changes in bioclimatic zones.

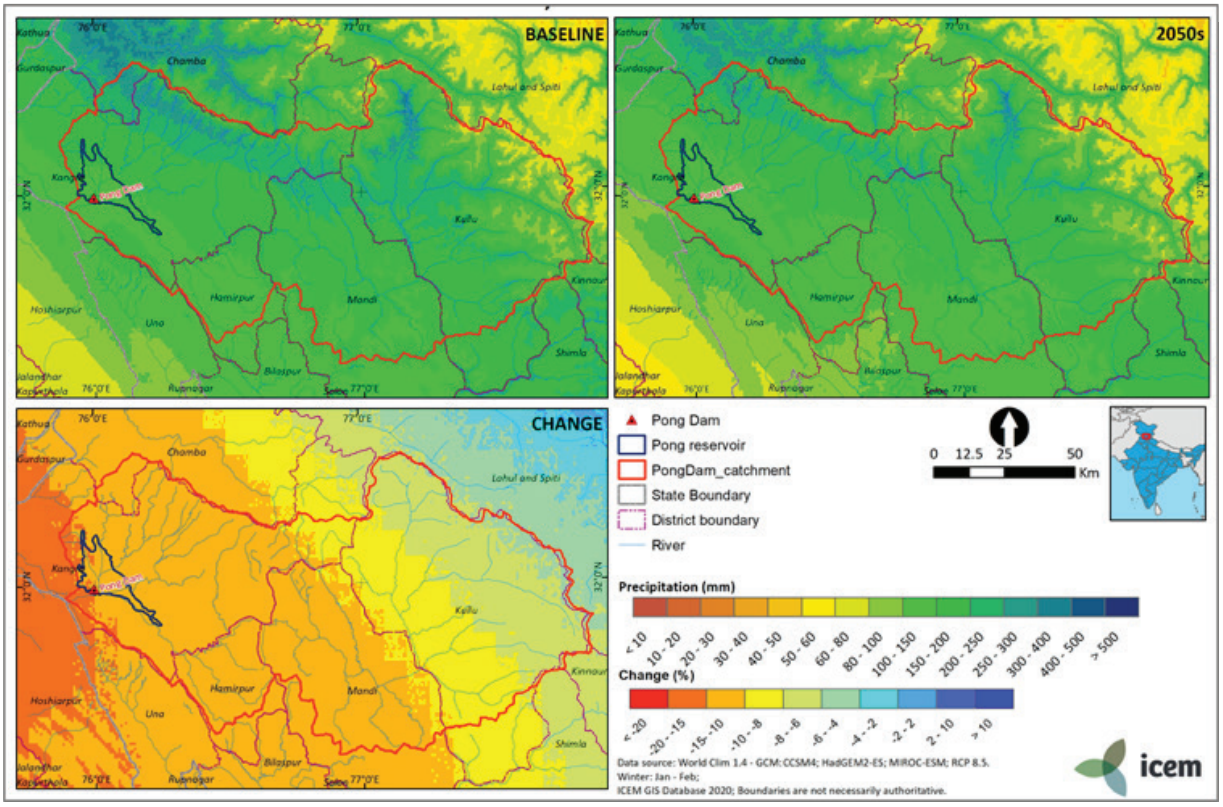


Figure 39 *Climate change zonal map – changes in annual precipitation In Pong Dam Lake Basin.*

9.1.8 Ecosystem-based adaptation planning

Adaptation measures can be taken to address different stages of the vulnerability assessment cycle. Threats of climate change are best addressed through mitigation measures, by minimising the extent to which the asset is exposed to the climate event, or by reducing the sensitivity of the asset. Reduction of non-climate threats is also considered as an adaptation option. Perhaps the most straightforward adaptation measures may be through building the adaptive capacity of the asset or of the management agency and wetland users (Figure 40).

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

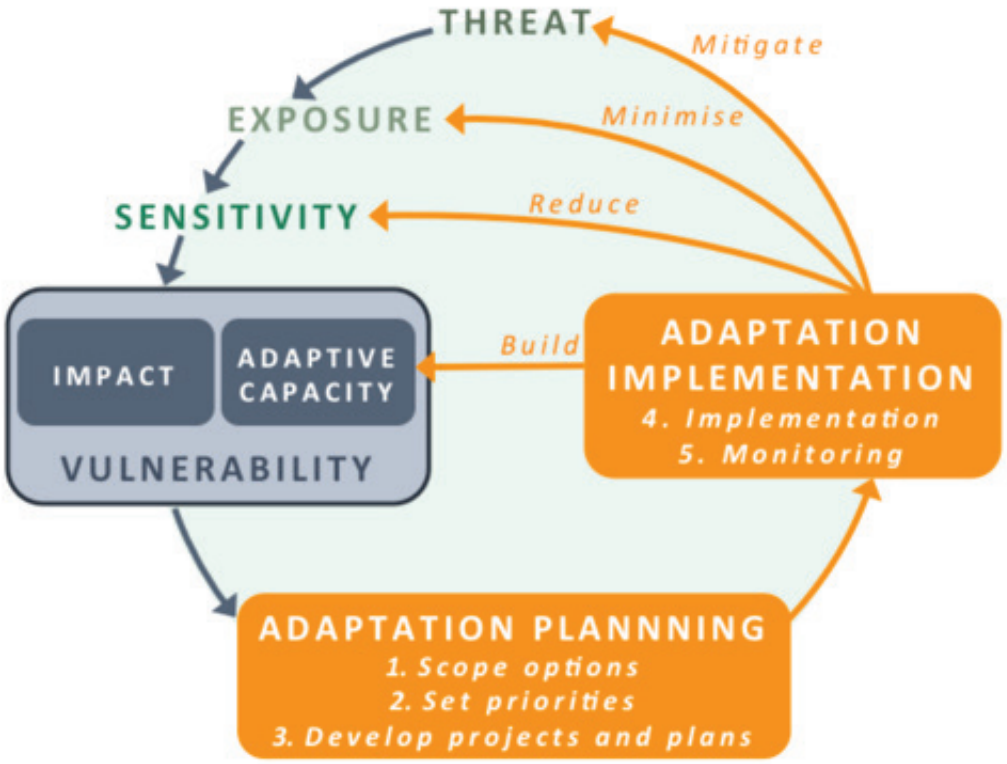


Figure 40 *Schematic of adaptation options to address climate change impacts on an asset*

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 recognises 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
- 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 41). 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.

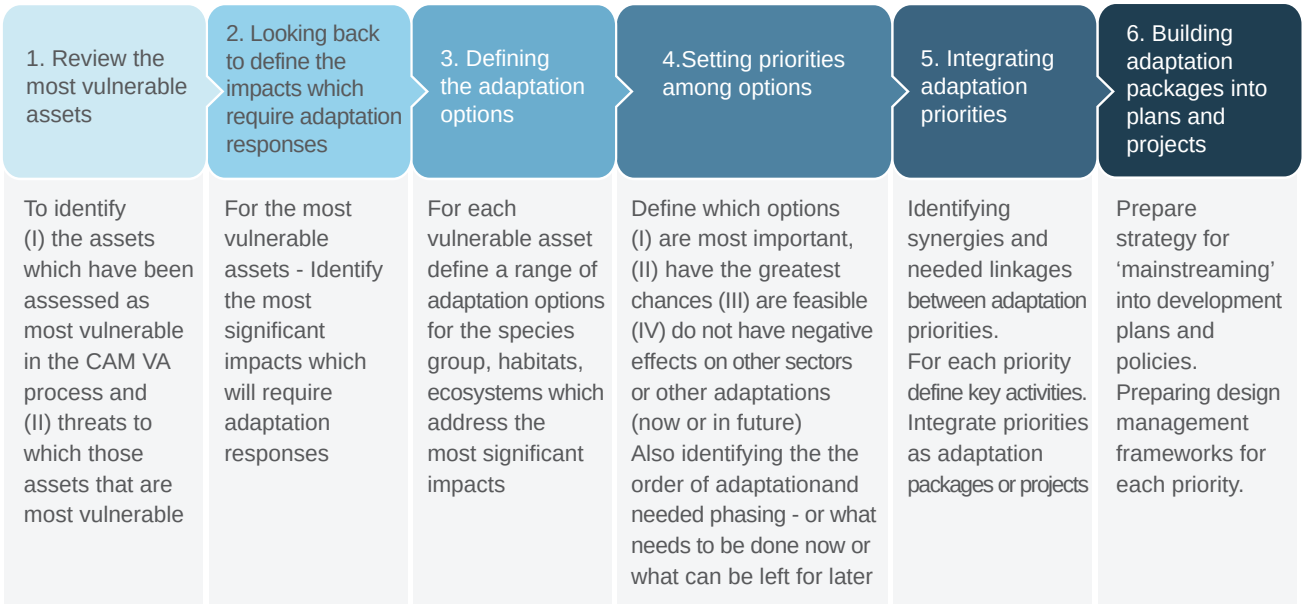


Figure 41 *CAM Adaptation Planning process*

Table 22 outlines the ecological principles and options for EbA to be considered in developing the adaptation plans for each of the Ramsar 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 22 *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

Principle	Description	Adaptation options
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 will 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 23 and prioritised using the adaptation matrix of feasibility and Table 24.

Table 23 *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 24 *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 Figure 29 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 25 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 levels to 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				

[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 – VULNERABILITY ASSESSMENT MATRICES

The matrices are attached as complemented materials.

Table 26 *Target assets and associated attached files for Vulnerability Assessment (VA)*

Target asset	Attached file
Catchment - surrounding hillsides	AAS2010-REP-004-02 Final Report Renuka Lake (Annex 2.1 VA_Catchment).docx
Shallow water on the sides providing a habitat for birds and dry bank areas providing nesting ground for turtles	AAS2010-REP-004-02 Final Report RenukaLake (Annex 2.2 VA_Habitats).docx
Aquatic grasses providing food for waterbirds	AAS2010-REP-004-02 Final Report RenukaLake (Annex 2.3 VA_AquaticGrass).docx
Golden Mahseer	AAS2010-REP-004-02 Final Report RenukaLake (Annex 2.4 VA_GoldenMahseer).docx
Turtles	AAS2010-REP-004-02 Final Report RenukaLake (Annex 2.5 VA_Turtles).docx
Recreation, tourism, religious tourism	AAS2010-REP-004-02 Final Report RenukaLake (Annex 2.6_VA_Tourism).docx

Photo credit: JoblessStudios.GIZ

9.2 Annex 2 – Vulnerability Assessment Matrices

Annex 2.1 - Vulnerability Assessment Matrix for the Catchment

ASSET NAME: CATCHMENT- SURROUNDING HILLSIDES

ASSET DESCRIPTION: The catchment area of Renuka wetland area having seasonal streams, springs and is covered with forest. The total catchment area of the lake is about 500 ha which is covered with sub-tropical vegetation. The entire catchment area is a reserve forest and has been declared a wildlife sanctuary. The Renuka Wetland covers an area that marks the northern boundary with old natural Sal forest where Sal is found mixed with all its major dry deciduous associates, including over-wood trees *Terminalia tomenstosa, Shorea robusta* (Sal), *Moringa pterygosperma, Ougeinia dalbergioides, Cassia fistula (Amaltas), Bauhinia variegate* (Kachnar), *Ficus palmata, Ficus religiosa* (Anzir), *Bambusa arundinacea, Phoenix* spp., *Salix tetrasperma* and *Dalbergia sissoo.* The area also supports a good population of Sambar, Barking deer and Goral.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**High**[1]	**High**[2]	**High**	**Direct impacts:** • With high rainfall and increased intensity of rainfall with a shorter duration, the degraded catchment area will be having high soil erosion. • With the degradation of the catchment area having less forest cover the water holding capacity will decreasing hence leading to higher water runoff of the hill slopes. • With more days of high-intensity rainfall, there will be more chances of flooding. **Indirect impacts:** • With more rainfall comes flooding that will lead to inundation of the banks that will lead to Loss of habitat.	**Very Low**[3]	**Very High**

[1] Any increased rain will have a negative impact as at present the catchment area is degraded and soil erosion-prone and not ready to absorb extra moisture, the increased rainfall is already leading to runoff from the hills and soil erosion. The water holding capacity of the catchment is also low. The catchment area is highly sensitive to erosion having seasonal perennial streams and high rainfall during monsoon will lead to high silt load being brought down to the lake.

[2] Any future increase will only aggravate the situation and a long term decrease in groundwater recharge impacting the lake water adversely. Also, With the current infrastructure development going on the catchment area is prone to soil erosion and it will lead to a high rate of soil erosion.

[3] With high silt load and limited institutional and financial capacity, the catchment area is highly vulnerable until preventive soil conservation measures are adopted.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• With increased runoff and loss of water holding capacity of the catchment area, there will be reduced ground water recharge. • Increased eutrophication leading to increased organic load with an effect on fish and turtles. • With the accumulation of more silt, the lake is getting shallower.		
Decrease of rainfall during the dry season (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post-Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**Medium**[4]	**Medium**[5]	**Medium**	**Direct impacts:** • Less ground water recharge • Impacts on habitats **Indirect impacts:** • Increase in aridity with a possible shift of some plant species towards higher reaches.	**Very Low**[6]	**High**
TEMPERATURE							
Increase of temperature during Winter (Jan-Feb)	By 2050s, maximum temperature increases from 19.2 to 22.0ºC (increasing by 2.8ºC).	**High**[7]	**High**[8]	**High**	**Direct impacts:** • The growth of certain plants that need winter chill or lower temperature may get affected. • Species pertaining to milder or warmer temperatures may alter the bio-diversity of the forest.	**Very Low**[9]	**High**

[4] Maximum rain is received during the monsoon. Though less rain will impact the groundwater recharge but not on a larger scale. Also, the water in the lake is not dependent on winter rain.
[5] It may affect the groundwater recharge and loss of soil moisture, but the effect will not be of higher magnitude as the season is usually dry.
[6] This is a natural phenomenon hence can be counteracted only by adopting suitable measures for better soil and water conservation.
[7] An increase in temperature will not be conducive towards the growth of plant species needing winter chill and at the same time, the plant species with adaptability to milder temperature will dominate.
[8] This will lead to a change in the forest mix.
[9] Though the forest department is aware of the changes and some efforts are being made but still, a lot of capacity needs to be built up for tackling this change.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					Indirect impacts: • Encourage hardier species and increase in the growth of invasive species		
Increase of temperature during Summer (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**High**[10]	**Very High**[11]	**Very High**	**Direct impacts:** • It may lead to dryness and increased mortality in forests • Change in biodiversity • Negatively impact plants that are vulnerable to heat stress • More fire incidents leading to more tree mortality **Indirect impacts:** • The plants unable to cope with the heat will vanish or shift to higher and cooler altitudes	**Low**[12]	**High**
Increase of temperature during Monsoon (Jun-Sept)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**medium**[13]	**medium**[14]	**medium**	**Direct impacts:** • The growth of certain plants that need winter chill or lower temperature may get affected. • Species pertaining to milder or warmer temperatures may alter the bio-diversity of the forest.	**medium**[15]	**Medium**
Increase of temperature during Post-Monsoon (Oct-Dec)	By 2050s, maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC).	**High**[16]	**High**[17]	**High**	**Direct impacts:** • Alter the bio-diversity as it will impact the tree growth or survival of the plants needing winter chill. • Impact the plant growth • It may have a positive impact on plant growth but at the same time may alter the biodiversity	**Low**[18]	**High**

[10] Low resilience of current forest stock to grow with the increase in temperature.
[11] More incidences of fire and more mortality of the trees with low heat tolerance.
[12] Some efforts are being made to introduce the plant species which can handle the increased temperature. Low natural capacity. The dominant species is Sal as it has good water holding capacity and for the adaption measure, more emphasis should be given to planting Sal trees. Rejuvenation of salt is very high.
[13] If the rains are in time and proper volume the plant growth will be moderately enhanced but the temperature increase is still in the threshold. The growth rate will be enhanced.
[14] With timely rain, the plant growth will not be affected but if no rain or insufficient rain will negatively impact the growth rate and may lead to degradation of forests.
[15] Though forest stands can be of mixed species the adaptive capacity can't be built up to tackle the increase or decrease of temperature.
[16] This will affect the growth of the species needing the winter chill as the growth will be stunted and will lead to change in bio-diversity.
[17] The area is usually dry during the winter season with less rainfall and the plant growth already slows down during the winters but with the increase in temperature during winter the growth of plants needing winter chill will be further affected.
[18] Existing forest nurseries are not geared up to cater to the current need.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Flash Flooding	Higher intensity of rainfall during the rainy season will threaten the Ramsar site with a higher risk of flash flooding.	Very High[19]	Very High[20]	Very High	**Direct impacts:** • With floods, the degraded catchment area will be having high soil erosion • With the degradation of the catchment area having less orest cover the water holding capacity will decreasing hence leading to higher water runoff of the hill slopes.	Very Low[21]	Very High
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar site.	High[22]	High[23]	High	**Direct impacts:** • With droughts, the temperature will increase and will lead to higher thermo-evaporation. • Less rainfall or no rainfall will lead to less percolation of water leading to low recharge of catchment areas. • Though the water in the lake is not directly dependent on rainfall on springs inside the lake but with less rainfall and ess water recharge the springs aquifers will also dry up leading to decreased lake water levels. • The dry banks and the shallow water provide habitat to the turtles and the migratory birds. With the drought, the silted banks will become more dryer making it impossible for turtles to make nests and the shallower water will move inland providing a lesser area for the keystone species for nesting hence leading to drying & loss of habitat. • Drought will lead to higher mortality of flora • With the drought, the catchment area will have more plant mortality so there wil lesser food availability.	Very Low[24]	Very High

[19] The catchment area is highly sensitive to erosion having seasonal perennial streams and high rainfall during monsoon will lead to high silt load being brought down to the lake.
[20] With the current infrastructure development going on the catchment area is prone to soil erosion and it will lead to a high rate of soil erosion
[21] With high silt load and limited institutional and financial capacity, the catchment area is highly vulnerable until preventive soil conservation measures are adopted.
[22] More fire incidences, lower water availability will lead to more plant mortality hence making the catchment area more degraded.
[23] With more degradation in the catchment area, a larger area will be exposed to erosion in case of heavy rain or flood.
[24] Natural phenomenon hence the adaptive capacity will be low until suitable measures are taken to rejuvenate the degraded forest catchment.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Decrease in the population of some forest species. • Vanishing of species unable to cope with heat stress and lesser water availability. **Indirect impacts:** • With the drought, the fire incidences will increase		
Fires	A higher temperature in the hot season causes a higher risk of forest fires.	Very High[25]	Very High[26]	Very High	**Direct impacts:** • Increase in Forest Stand Mortality. • Loss of wildlif • Food availability will be affected • Loss of soil moisture • Negative impact on ground water recharge capacity **Indirect impacts:** • Fire is leading to more inorganic input into the lake.	Very Low[27]	Very High

[25] During fire season the soil moistures dry up leading to more fire in the catchment area.

[26] With lower moisture content in the soil and higher temperature, the catchment area is exposed to fire. Fire will lead to the loss of plants and wildlife and also will lead to a shortage of food.

[27] The adaptive capacity is low as there are not enough funds and capacity available to fight the fire incidences.

Annex 2.1.1 - Scoring matrices

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

Figure 1 *Determining impact score from sensitivity and exposure*

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

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

Annex 2.2 - Vulnerability Assessment Matrix for Habitats

ASSET NAME: SHALLOW WATER ON THE SIDES PROVIDING A HABITAT FOR BIRDS AND DRY BANK AREAS PROVIDING NESTING GROUND FOR TURTLE

ASSET DESCRIPTION: These are the two distinct habitats present in the Renuka Wetland. One is the Shallow water habitat for migratory birds created by the silt brought down by the seasonal streams and the other is the dry bank areas providing nesting ground for turtles.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**High**[1]	**High**[2]	**High**	**Direct impacts:** • Initially, the silt brought down to the lake proved beneficial for the migratory birds but it is going to reverse now as excessive rainfall will lead to excessive siltation filling up of shallow water and eventually turning them into dry banks faster which is not needed at all. • Since the lake size is small so is its carrying capacity. As eutrophication is high any new sediment load into the lake is silently leading to its death, the area and dry banks will increase but at the cost of narrowing down the habitat for migratory birds & turtles every passing year. • It will lead to a geographical shift in the habitat. • Water levels will change only with flooding or flash flooding	**Very Low**[3]	**Very High**

[1] More rainfall during the monsoon season of the preceding year leads to loss of nesting habitats for Bengal Roofed Turtle. Also, with excessive rain, the silt load will also increase if proper silt detention measures are not adopted leading to more silt deposition and a decrease in shallow water availability thus loss of habitat for migratory birds.

[2] It will lead to a decrease in the number of nests for turtles leading to a decrease in the turtle population. With the loss of habitat for migratory birds, the number of migratory birds will also decline. The number of nests in B. kachuga was significantly negatively correlated with total precipitation in the immediately preceding year. Presumably, total precipitation may affect the amount of nesting habitat available or the availability of some other limiting resource. Ref: Variation in Reproductive Output of the Red-crowned Roofed Turtle (Batagur kachuga) and the Three-striped Roofed Turtle (Batagur dhongoka) in the Chambal River of North India. Article in Chelonian Conservation and Biology · December 2017.

[3] The adaptive capacity is very low as nothing can be done regarding the increase in rainfall. Also, with increasing construction of roads in the catchment area without proper silt detention measures is leading to an increase in silt load. The institutional adaptive capacity needs to be built up with proper financial support. With proper silt detention measures and awareness orientation programs are adopted then the vulnerability can be handled.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during the dry season (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post-Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**Low**[4]	**Medium**[5]	**Medium**	**Direct impacts:** • Less recharge of spring aquifers	**Medium**[6]	**Medium**
TEMPERATURE							
Increase of temperature during Summer (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**High**[7]	**High**[8]	**High**	**Direct impacts:** • An increase in temperature will dry the filled up silted areas faster turning the lake areas into dry banks • Excessive temperature will lead to increased evapo-transpiration of lake water. • It will directly have an impac on food availability and may lead to a change in the biodiversity of the lake • Cause algae blooms	**Very Low**[9]	**High**

[4] It may have a very moderate impact as the lake is fed by internal aquifers which are recharged during monsoon season. No adverse effect as during these months turtles is nesting on the dry sandbanks. As for migratory birds during winters they need shallow water for nesting.

[5] As for turtles it will not make much difference due to a decrease in rainfall but for migratory birds, it will affect the habitat as the shallow water will shift further inland but with more silt deposition during monsoon, it may lead to loss of habitat for migratory birds.

[6] Adaptive capacity will be medium as with proper silt control measures the habitat can be saved.

[7] Though there are no migratory birds this time of the year during this time for turtles hatching of eggs are going on and the increase in temperature may lead to enhance the rate of development and may lead to a change of gender.

[8] The change in temperature may lead to changes in micro-climatic conditions.

[9] Natural adaptive capacity will be low as there is low or no technical support for habitat management.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during Monsoon (June-Sept)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**Medium**[10]	**Medium**[11]	**Medium**[12]	**Direct impacts:** • Decrease in the dissolved oxygen • Food chain affected	**Low**[13]	**Medium**
Increase of temperature during Post-Monsson (Oct-Dec)	By 2050s, maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC).	**High**[14]	**High**[15]	**High**	**Direct impacts:** • With increased temperature during the post-monsoon period will make the banks drier and it will not be possible for turtles to make nests as they are hole nesters hence they will be needing the muddy dry banks for nesting. This will lead to a shift in the nesting and hatching period of turtles. • Reduce the active reproductive period. • Effect on the habitat of migratory birds • Increase Invasive grasses • Reduced area of the lake due to drying. • Increase in weed reducing the area of the lake.	**Low**[16]	**High**
EXTREME EVENTS							
Flash Flooding	Higher rainfall during the rainy season will threaten the Ramsar site with a higher risk of flash flooding.	**High**[17]	**High**[18]	**High**	**Direct impacts:** • Increase sediment in the lake affecting the shallow water as well as the dry banks leading to a reduction in the size of the lake.	**Very Low**[19]	**Very High**

[10] It will have an impact on turtle habitat as the coming period of Oct-May is their nesting and hatching period.

[11] As this is the wettest season increase in temperature will only have a big impact if it is followed by low rains during this season.

[12] An increase in the air temperature will cause water temperatures to increase as well. As water temperatures increase, dissolved oxygen levels decrease, and many aquatic habitats will be negatively affected.

[13] Natural phenomenon and less knowledge about habitat management.

[14] Shift in temperature will lead to a change in the reproductive period as turtles need a certain temperature for nesting. It will also be detrimental for migratory birds as they will not be able to get the proper temperature for their winter habitat. (Shashwat Sirsi, Shailendra Singh, Ashutosh Tripathi, Shawn F. McCracken, Michael R.J. Forstner, Brian D. HornVariation in Reproductive Output of the Red-crowned Roofed Turtle (Batagur kachuga) and the Three-striped Roofed Turtle (Batagur dhongoka) in the Chambal River of North India. Article in Chelonian Conservation and Biology · December 2017- https://bioone.org/journals/chelonian-conservation-and-biology/volume-16/issue-2/CCB-1236.1/ Variation-in-Reproductive-Output-of-the-Red-crowned-Roofed-Turtle/10.2744/CCB-1236.1.short .

[15] Eutrophication is happening and is clearly visible on the periphery which will further reduce the lake area for birds, fishes, turtles and other species.

[16] Natural phenomenon and no technical knowledge of habitat management.

[17] Though there may be shifting of habitat the scope of finding suitable habitat for turtles is very limited as the lake area is limited and is narrowing down.

[18] Closed area with little scope of migration or shifting of habitat.

[19] Various conservation measures are needed to change the current scenario otherwise the adaptive capacity will remain low.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar site.	**High**[20]	**High**[21]	**High**	Direct impacts: • Drought will have a negative impact on habitat • It will have a drastic impact on ground recharge and lake water availability and shallow water areas may dry up. • It will lead to increased dry banks. • Shifting of habitat	**Low**[22]	**High**

[20] Exposure of habitat to prolonged dry season climate change may lead to a geographic shift of habitat.

[21] The dry season is basically the winter season or post-monsoon season when migratory birds start coming to the lake area. With less rainfall, the area with shallow water will reduce hence making migratory birds move further down leading to shifting of habitat.

[22] Natural adaptive capacity will be low because ecological changes or environmental changes have to be addressed by a proper catchment area treatment plan.

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 Aquatic Grasses

ASSET NAME: AQUATIC GRASSES PROVIDING FOOD FOR WATERBIRDS

ASSET DESCRIPTION: Renuka Wetland is a vital habitat for both terrestrial and aquatic organisms, and it is also the winter home of a wide range of migratory bird species. Aquatic grasses are a critical part of ecosystems; they provide food and habitat for various aquatic species and birds. They also help keep the water clear and healthy by absorbing nutrients, trapping sediments, reducing erosion and adding oxygen.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**High**[1]	**High**[2]	**High**[3]	**Direct impacts:** • Increased turbidity • Reduction in compensation depth[4], below which light intensity is insufficient to sustain photosynthesis. • Decrease in growth/production of aquatic grasses as silt load increases during this period	**Low**[5]	**High**
Decrease of rainfall during the dry season (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post- Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**Medium**[6]	**Medium**[7]	**Medium**[8]	**Direct impacts:** • It will have a no or very mild negative impact as the lake water is dependent on internal springs which in turn are dependent on monsoon so not much impact during the dry season.	**High**[9]	**Medium**

[1] With the increase in silt load, the turbidity will increase which in turn will lead to loss of aquatic grasses their biodiversity and productivity. Also, in the backdrop of the increased Eutrophication of the lake, the growth of aquatic grasses will be negatively impacted. Light attenuation by inorganic turbidity decreases the fraction of light absorbed by photosynthesising organisms in lakes. This has been shown to reduce the density, growth rates and production of lake phytoplankton considerably (Ian Donohue & Jorge Garcia Molinos, 1994; Guenther & Bozelli, 2004a).

[2] With high silt load the survival of grasses will be a challenge. Decreased transmission of light through the water column is among the most important of the physical effects of increased sediment loads on aquatic ecosystems. The absorption and scattering of light by suspended particles reduces the compensation depth, below which light intensity is insufficient to sustain photosynthesis, thus diminishing the volume of water supporting primary production considerably (Ian Donohue & Jorge Garcia Molinos, 1994; Guenther & Bozelli, 2004a).

[3] High rates of sediment accumulation can lead to reduced depth and ecosystem services of water bodies and degraded water quality (Karl Havens and Erik Jeppesen, 2018: Ecological Responses of Lakes to Climate Change).

[4] The compensation point, the depth where photosynthesis equals respiration.

[5] Climatic conditions cannot be tackled but efforts can be made to capture the silt load by undertaking suitable silt detention measure.

[6] The lake is fed through springs which in turn are not dependent on rain for its recharge.

[7] As the exposure to low rainfall is medium it will not be affecting the aquatic flora to a degree where it needs to adapt itself for the climate change.

[8] With medium exposure and sensitivity, there will be an almost negative impact on the growth of aquatic grasses hence the impact level will be low.

[9] The adaptive capacity this threat regarding aquatic grasses will be high as the grasses does not require any special treatment for adaptation.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during Winter (Jan-Feb)	By 2050s, maximum temperature increases from 19.2 to 22.0ºC (increasing by 2.8ºC).	**High**[10]	**High**[11]	**High**[12]	**Direct impacts:** • Increased winter temperature leads to an increase in productivity. • But it may also induce new or invasive plants	**Low**[13]	**High**
Increase of temperature during Summer (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**High**[14]	**High**[15]	**High**[16]	**Direct impacts:** • Increase in growth of aquatic plants. • But it may also induce new or invasive plants. • Warmer summer leads to Increased incidences of algal bloom • it may lead to acceleration in drying up of the lake periphery thereby leading to low output	**Low**[17]	**High**
Increase of temperature during Monsoon (Jun-Sept)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**Medium**[18]	**Medium**[19]	**Medium**[20]	**Direct impacts:** • Hot and humid temperatur provides an ideal atmosphere for growth and it will have a positive impact on aquatic plant growth provided rains are sufficient.	**Low**[21]	**Medium**

[10] Warming generally stimulates aquatic plant growth (Peiyu Zhang et al., 2018 - Effects of Rising Temperature on the Growth, Stoichiometry, and Palatability of Aquatic Plants).

[11] It will lead to thermal stratification and will impact the water quality.

[12] The increase in temperature can influence the length of the growing season with consequent increases in bacterial and phytoplankton productivity (Woolway et al., 2019 - Substantial increase in minimum lake surface temperatures under climate change- page 92).

[13] As this is natural phenomenon, the adaptive capacity will be low as the plants will not be able to adapt to this increased temperature.

[14] Increasing temperature generally accelerate growth and development rates of individual organisms, although changes in absolute abundances tend to be species-specific (Rita Adrianet al., 2009)

[15] Climate may also affect species diversity and composition through the invasion of non-native species that expand their geographical range as water temperatures warm (Rita Adrianet al., 2009).

[16] Climate Change and Harmful Algal Blooms https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms.

[17] As this is natural phenomenon, the adaptive capacity will be low as the plants will not be able to adapt to this increased temperature.

[18] There is high precipitation, and it is usually hot and humid during this season.

[19] Because usually during this season the plant growth is already accelerated.

[20] Due to natural dependency on high temperature for increased plant growth the impact will also be medium.

[21] Natural phenomenon as nothing can be done to increase the adaptive capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during Post-Monsoon (Oct-Dec)	By 2050s, maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC).	**High**[22]	**High**[23]	**High**[24]	**Direct impacts:** • Increased winter temperature leads to an increase in productivity. But it may also induce new or invasive plants	**Low**[25]	**High**
EXTREME EVENTS							
Flash flooding	Higher rainfall during the rainy season will threaten the Ramsar site with a higher risk of flash flooding.	**High**[26]	**High**[27]	**High**[28]	**Direct impacts:** • It will have a negative impact. • Increased turbidity • Reduction in compensation depth, below which light intensity is insufficient to sustain photosynthesis. • Decrease in growth/production of aquatic grasses as silt load increases during this period. • Runoff from catchment areas transport nutrients and sediments into lake ecosystems • It may impact the population of aquatic organisms	**Low**[29]	**High**
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar site.	**High**[30]	**High**[31]	**High**	**Direct impacts:** • Since spring recharge are dependent on catchment recharge so any drought will have an impact if it is for a prolonged period impacting catchment recharge. • Droughts may lead to heat stress.	**Low**[32]	**High**

[22] Warming generally stimulates aquatic plant growth (Peiyu Zhang et al., 2018 - Effects of Rising Temperature on the Growth, Stoichiometry, and Palatability of Aquatic Plants).

[23] It will lead to thermal stratification and will impact the water quality.

[24] The increase in temperature can influence the length of the growing season with consequent increases in bacterial and phytoplankton productivity. (Woolway et al., 2019 - Substantial increase in minimum lake surface temperatures under climate change- page 92).

[25] As this is natural phenomenon, the adaptive capacity will be low as the plants will not be able to adapt to this increased temperature.

[26] Changes in seasonal patterns of precipitation and runoff will alter hydrologic characteristics of aquatic systems, affecting species composition and ecosystem productivity. Populations of aquatic organisms are sensitive to changes in the frequency, duration, and timing of extreme precipitation events, such as floods. (N.LeRoy Poff et al., 2002 - Aquatic ecosystems & Global climate change)

[27] With high silt load the survival of grasses will be a challenge. Decreased transmission of light through the water column is among the most important of the physical effects of increased sediment loads on aquatic ecosystems.

[28] High rates of sediment accumulation can lead to reduced depth and ecosystem services of water bodies and degraded water quality (Karl Havens and Erik Jeppesen, 2018 - Ecological Responses of Lakes to Climate Change)

[29] Climatic conditions cannot be tackled but efforts can be made to capture the silt load by undertaking suitable silt detention measures.

[30] Prolonged dry season will impact the recharge of the spring aquifer. The internal springs in the lake are the main source of the lake water and with less spring recharge due to drought the spring water output will be impacted leading to drying of lake further impacting the aquatic grasses and causing a rippling effect.

[31] Temperature increases in lakes during drought impacting the ecology. Drought may also expose water plants to damage and heat stress.

[32] The natural capacity of the lake to adapt to this threat is low and also being the natural phenomenon nothing much could be done.

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 Golden Mahseer

ASSET NAME: GOLDEN MAHSEER

ASSET DESCRIPTION: Golden mahseer, *Tor putitora* Hamilton, one of the largest freshwater fish of the Indian sub-continent, inhabits mainly Himalayan rivers in the foothills. Golden Mahseer has suffered severe population decline in much of its distribution range and is now listed as endangered on IUCN Red List. Mahseers are critical across the Indian Himalayan biodiversity hotspot; however, multiple human stressors compounded by climate change have significantly depleted their populations over recent decades.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**High**[1]	**High**[2]	**High**	**Direct impacts:** • May lead to lesser space availability for fishes due to increased silt flow impacting its natural habitat • It will have an impact on its natural food availability • May impact its breeding as shallow water may be highly silted • It may also impact shallow water during the spawning period and may fill it with silt leading to the kill of eggs and fingerlings.	**Medium**[3]	**High**
Decrease of rainfall during the dry season (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post-Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**Low**[4]	**Low**[5]	**Low**	**Direct impacts:** • A decrease in rainfall will have very little or no impact as the peak spawning period is during the monsoon **Indirect impacts:** • As the overall lake is in the eutrophication phase already, decreased rainfall in the catchment will impact underground spring discharge leading to degeneration and a faster eutrophication process	**Low**[6]	**Medium**

[1] Large volume of water does not provide a conducive environment for the breeding of Mahseer as it needs shallow water having pebbles and gravel

[2] Mahseer during its peak spawning period during monsoon moves towards shallow waters and due to excess siltation that may pose as a threat to eggs.

[3] Adaptive capacity may be directly relating to the natural habitat capacity of ecosystems and species or indirect relating to management capacity.

[4] Decrease in rainfall will not affect Mahseer as its peak spawning period is during the monsoon.

[5] Production of Mahseer will not be affected.

[6] Adaptive capacity may be directly relating to the natural habitat capacity of ecosystems and species or indirect relating to management capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the SW Monsoon (Jun-Sep)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**High**[7]	**High**[8]	**High**	**Direct impacts:** • will alter the surface water temperature which in turn may directly impact its breeding as fish prefers to breed in colder waters	**Low**[9]	**Very High**
Increase of temperature during the hot dry season (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**Medium**[10]	**Medium**[11]	**Medium**	**Direct impacts:** • Higher evapotranspiration in future will impact lake water availability for the fishes • Acceleration in lake drying & further squeezing the available area and Increase in dry zone areas, leading to the lesser area to swim	**Low**[12]	**Medium**
Increase of temperature during the cold dry season (Oct–Feb)	During post-monsoon (Oct-Dec), maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC). During Winter (Jan-Feb), maximum temperature increases from 19.2 to 22.0ºC (increasing by 2.8ºC).	**Medium**[13]	**Medium**[14]	**Medium**	**Direct impacts:** • An increase in temperature may not have a negative impact and maybe some positive impact as usually low winter temperature impacts growth	**Low**[15]	**Medium**

[7] Mahseer requires cold water temperature for spawning during monsoon hence, high temperature will pose risk.

[8] The fish prefers to continue mostly with perennial water sources and cooler temperatures.

[9] No possibility of natural adaptation to this range of high temps.

[10] Higher arid environment will be detrimental to the growth of fish.

[11] Less availability of water

[12] No possibility of natural adaptation to increase in temperature during hot dry season

[13] The spawning grounds are characterized by water temperature varying from 11 to 30.5 °C, alkaline pH and dissolved oxygen concentration in the range of 6.4–11 mg/l. The physico-chemical nature of the feeding grounds is characterised by water temperature in the range of 14–22 °C and an alkaline pH (>7). Dissolved oxygen in these habitats varies from 5.2 to 12.9 mg/l

[14] The fish prefers mostly cooler temperatures .

[15] Natural adaptive capacity is low to address these changes.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Flood	Higher rainfall during the rainy season will threaten the Ramsar site with a higher risk of flash flooding.	**High**[16]	**High**[17]	**High**	**Direct impacts:** • As the intensity of rain has increased over the years and with it Flash flooding, it brings a very high load of silt and it has already a very high impact, prime reason for lake dying and destroying the large fish habitat • Flash floods impact fertilized eggs and the shallow habitat	**Low**[18]	**High**
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar site.	**High**[19]	**High**[20]	**High**	**Direct impacts:** • Drought conditions always negatively impact fish leading to higher mortality • It will alter or reduce the natural food availability	**Low**[21]	**High**
Fires	A higher temperature in the hot season cause a higher risk of forest fires.	**High**[22]	**High**	**High**	**Direct impacts:** • Not much impact on fish directly **Indirect impacts:** • Forest fires can reduce the catchment capacity of natural rain-water recharge and its spring feeding capacity • Overall, it may moderately impact the vegetation cover in the surroundings • Low forest tree cover may lead to evapotranspiration	**Low**[23]	**High**

[16] Large volume of water, high discharge and higher number of predators do not constitute a conducive environment for ova and fry of mahseer.

[17] Fertilized eggs can sink and perish.

[18] As the only outlet for the overflow water is narrow and is slowly being filled with sediments with no proper management plan and with low institutional and financial support the adaptive capacity is quite low.

[19] Due to drought conditions, the spawning grounds are shallow due to low water discharge and it will lead to high mortality.

[20] Drought will lead to a high rate of mortality

[21] Overall Natural Adaptive capacity will be low.

[22] Less water recharge leading to low water output from springs

[23] Less institutional support and financial support are available for tackling forest fire.

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

Annex 2.5 - Vulnerability Assessment Matrix for Turtles

ASSET NAME: TURTLES

ASSET DESCRIPTION: The *Batagur* and *Nilssonia* spp. turtles found in the deepwater of Renuka Wetland with terrestrial nesting sites and are the most threatened freshwater turtles in India. The Red-Crowned Roof Turtle, *Batagur kachuga,* is listed as Critically Endangered on the IUCN Red List of Threatened Species. *Nilssonnia gangetica* and *Nilssonia hurum* are both listed as Endangered. The Red-crowned Roof Turtle is listed as schedule 1 of the Indian Wildlife Protection Act 1972 and is listed on Appendix II of the Convention on International Trade in Endangered Species (CITES).

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**Very High**[1]	**Very High**[2]	**Very High**	**Direct impacts:** • With increased rainfall or increased intensity of rainfall, the soil erosion will be increased leading to increased siltation deposition and eutrophication which will further lead to Loss of habitat. • With increased eutrophication less dissolved oxygen, food availability will also decrease • Decrease in the population of turtles.	**Very Low**[3]	**Very High**
Decrease of rainfall during the dry season (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post-Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**High**[4]	**High**[5]	**High**	**Direct impacts:** • Decrease in underground spring discharge • It can have a double blow because the outer periphery is already filled up with silt, with decreased rainfall the low spring discharge may lead to quick-drying out into a dry surface. • That may lead to loss of food or a decrease in food availability.	**Low**[6]	**High**

[1] Peak nesting activity occurs at the lowest river depth or maximum availability of nesting habitat but with increase in rainfall during the monsoon of the previous year there may be loss of habitat or area suitable for nesting habitat which will lead to a decrease in number of nests.

[2] The number of nests of B. kachuga have a negative correlation with total precipitation in the immediately preceding year. Ref: Variation in Reproductive Output of the Red-crowned Roofed Turtle (Batagur kachuga) and the Three-striped Roofed Turtle (Batagur dhongoka) in the Chambal River of North India.

[3] Adaptive capacity is very low as there is no institutional or technical support for habitat management.

[4] Decrease in nesting activity as B. kachuga are hole nesters with dry banks they will not be able to make nest and this will lead to shifting of habitat.

[5] Higher sensitivity with a reduction in area availability for nesting.

[6] Currently no habitat management capacity developed.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during Winter (Jan-Feb)	By 2050s, maximum temperature increases from 19.2 to 22.0ºC (increasing by 2.8ºC).	**High**	**High**	**High**	**Direct impacts:** • May have an impact on sex ratio as it is known that temperature variation may lead to change in sexual orientation during incubation in eggs of turtles, but conclusively we haven't got much information about this species in particular.	**Low**	**High**
Increase of temperature during Summer (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**Low**[7]	**Low**[8]	**Low**	**Indirect impacts:** • More evapotranspiration. • Drying up of lake banks and food supply	**Low**[9]	**Medium**
Increase of temperature during Monsoon (Jun-Sept)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**Medium**	**Medium**	**Medium**	**Direct impacts:** • Frequent extreme temperatures in summer will shrink the lake area further as the trend is already there. • Change in habitat around periphery & dry banks • An increase in water temperature may interfere or alter the present habitat leading to geographical shifting of habitat.	**Low**	**Medium**
Increase of temperature during Post-Monsoon (Oct-Dec)	By 2050s, maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC).	**Medium**[10]	**Medium**[11]	**Medium**	**Direct impacts:** • Shorter reproductive period. • Low egg-laying.	**Low**[12]	**Medium**

[7] This period does not correspond to breeding, nesting or hatching season hence there will be minimum effect.

[8] Increase in 2-3 degrees of temperature does not have any significant effect on B. kachuga.

[9] There will be a need to prepare a future management plan for effectively manage the micro-climatic conditions and habitat.

[10] Change of 2-3 degrees of temperate may enhance the rate of development.

[11] Temperature increase may bring about small changes in the micro-climatic conditions and habitat structure

[12] Adaptive capacity is very low as there is no institutional or technical support for habitat management.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Flash flooding	Higher rainfall during the rainy season will threaten the Ramsar site with a higher risk of flash flooding.	Very High[13]	Very High[14]	Very High	**Direct impacts:** • Loss of habitat • Lesser nests in the succeeding year	Very Low[15]	Very High
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect habitats in the Ramsar site.	High[16]	High[17]	High	**Direct impacts:** • Higher thermo-evaporation • Low recharge of catchment areas • Decreased lake water level • Drying & Loss of habitat • Lesser food availability • Decrease in the population of turtles	Very Low[18]	Very High

[13] Flooding of sandbank/riverbanks leading to loss of habitat.

[14] Nesting in the succeeding year will be affected.

[15] The site management is ill-equipped to deal with future planning and it will highly impact the key stone specie in the future.

[16] Water level reduction will lead to exposure to nesting and breeding habitat.

[17] Loss of habitat will lead to lesser nesting.

[18] No technical support for habitat management and fewer financial resources available.

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 Recreation, Tourism and Religious Tourism

ASSET NAME: RECREATION, TOURISM, RELIGIOUS TOURISM

ASSET DESCRIPTION: Religious tourism and yearly Fair is a big attraction. Wildlife sanctuary, Mini zoo, Boating is the other tourist attraction. For catering the tourists there is one HP Tourism Hotel beside HP Forest Rest House and rest house of Renuka Development Board. The tourists can also stay in the ashrams around the lake. But these do not provide adequate accommodation during the fair as large number of people come during those days and camp around the lake in the open ground.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun–Sep)	Increase by 12.6%, from 1789.5 mm to 2014.4 mm (+224.9 mm) by 2050s.	**High**[1]	**High**[2]	**High**[3]	**Direct impacts:** • With increased rainfall or increased intensity of rainfall, the soil erosion will be increased leading to increased siltation deposition and eutrophication which will further lead to Loss of habitat. • With increased eutrophication less dissolved oxygen, food availability will also decrease • Decrease in the population of turtles.	**Low**[4]	**High**
Decrease of rainfall during dry season. (Oct-May)	Decrease by 9.2%, from 133.5 mm to 121.2 mm (-12.3 mm) during Post-Monsoon (Oct-Dec) by 2050s. Decrease by 7.9%, from 143.8 mm to 132.5 mm (-11.3 mm) during Winter (Jan-Feb) by 2050s. Decrease by 6.0%, from 119.0 mm to 111.9 mm (-7.1 mm) during Summer (Mar-May) by 2050s.	**Medium**[5]	**Medium**[6]	**Medium**[7]	**Direct impacts:** • Will have a positive impact. During this time religious fair is organized. With less rain it will be convenient for more pilgrims to come. • Pleasant season with less rain will lead to more tourist flow	**Medium**[8]	**Medium**

[1] As this being a mountainous area and increased rain leads to blocked roads and disruption in transport that will lead to less tourist influx hence leading to loss of income.
[2] As all tourism and recreational activities are sensitive towards abnormal weather conditions any increased rainfall will have a negative impact.
[3] It will have an impact on all the tourism and recreation related activities and may lead to low income to the people dependent on tourism.
[4] As this is natural phenomenon the natural capacity to adapt is low.
[5] Any condition which leads to dry season during fair as well as bird watching will have a positive impact on tourism as with less rainfall the season will be milder and will be more convenient for the tourist to come.
[6] This season is generally dry hence will be less sensitive towards the threat.
[7] Medium impact as this is the time when religious fair is held.
[8] As this is natural phenomenon hence nothing can be done but with increased tourist influx the Ramsar site will be impacted.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during Winter (Jan-Feb)	By 2050s, maximum temperature increases from 19.2 to 22.0ºC (increasing by 2.8ºC).	**Medium**[9]	**Medium**[10]	**Medium**[11]	**Direct impacts:** • It will have a positive impact for tourism and recreational activities	**Low**[12]	**Medium**
Increase of temperature during Summer (Mar-May)	By 2050s, maximum temperature increases from 30.9 to 34.2ºC (increasing by 3.3ºC). But there is no or very little rainfall during Mar-May.	**Low**[13]	**Low**	**Low**	**Direct impacts:** • Will not have much impact as during this season there is less tourist inflow across Himachal **Indirect impact:** • Reduced pressure due to less tourists	**High**[14]	**Low**
Increase of temperature during Monsoon (Jun-Sept)	By 2050s, maximum temperature increases from 31.1 to 33.2ºC (increasing by 2.1ºC).	**High**[15]	**High**[16]	**High**[17]	**Direct impacts:** • It will have a negative impact as increased temperature coupled with high humidity will be not good for recreational and tourist activities	**Low**[18]	**High**
Increase of temperature during Post-Monsson (Oct-Dec)	By 2050s, maximum temperature increases from 24.2 to 27.0ºC (increasing by 2.8ºC).	**Low**[19]	**Low**[20]	**Low**[21]	**Direct impacts:** • Shorter reproductive period. • Low egg-laying.	**Low**[22]	**Low**

[9] Milder winter will boost tourism and recreational activities.
[10] Even with increased temperature the tourist influx will not be much impacted as the increase in temperature will be within the tolerable limits as compared to other lower areas.
[11] It will not have much impact on the tourisms as it is seen that for the last several years more tourists are flocking the hilly areas during winters.
[12] As the tourism department is not geared up to handle the increased tourist inflow.
[13] Less tourist inflow.
[14] With less tourist the adaptive capacity will be high as less work has to be done for catering to the tourist.
[15] With increased humidity and temperature less tourists will come leading the decrease in income of tourism operators
[16] Less number of tourist
[17] Increased temperature coupled with high humidity will not be good for recreational and tourism activities.
[18] Without proper backup from Government the tourism sector will not be able to handle this threat.
[19] Post monsoon season the birds start arriving which will boast tourism as temperature even after 3 degree increase will be well under tolerable limits for tourists as this will be early winter season.
[20] This season is generally dry hence will be less sensitive towards the threat.
[21] Medium impact as this is the time when religious fair is held.
[22] As this is natural phenomenon hence nothing can be done but with increased tourist influx the Ramsar site will be impacted.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Flash flooding	Higher rainfall during the rainy season will threaten the Ramsar site with higher risk of flash flooding.	**High**[23]	**High**[24]	**High**[25]	**Direct impacts:** • It will have a negative impact as flash flood will trigger landslides and soil erosion leading to road blockage. It will lead to less tourist influx and will impact the tourist industry.	**Low**	**High**
Drought	Lower rainfall in the dry season will cause intensive drought in surrounding areas and negatively affect tourism in the Ramsar site.	**High**[26]	**High**[27]	**High**[28]	**Direct impacts:** • It will have a negative impact leading to less tourist influx which will impact the livelihood of tourist operators.	**Low**[29]	**High**

23 Flooding will lead to landslides on roads which will have a negative impact on tourism and recreational activities.
24 All tourism and recreational activists get halted when such conditions prevail.
25 It will have an impact on livelihood activities related to tourism.
26 Tourists prefer mild and moderate climate for recreational and other activities but due to drought climate will be hot and dry leading to decrease in tourists.
27 Less tourist means less opportunity for income hence this will be at a higher level of exposure and sensitivity.
28 It will impact highly the tourism industry as it depends on number tourist during the season for overall yearly income.
29 Natural phenomenon hence, the natural adaptive capacity is low.

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 – ADAPTATION PLANNING MATRICES

The matrices are attached as complemented materials.

Table 27 *Target assets and associated attached files for Adaptation Planning (AP)*

Target asset	Attached file
Catchment - surrounding hillsides	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.1 AP_Catchment).docx
Shallow water on the sides providing a habitat for birds and dry bank areas providing nesting ground for turtles	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.2 AP_Habitats).docx
Aquatic grasses providing food for waterbirds	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.3 AP_AquaticGrass).docx
Golden Mahseer	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.4 AP_GoldenMahseer).docx
Turtles	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.5 AP_Turtles).docx
Recreation, tourism, religious tourism	AAS2010-REP-004-02 Final Report RenukaLake (Annex 3.6_AP_Tourism).docx

Photo credit: JoblessStudios.GIZ

3.1 - Adaptation Planning Matrix for the Catchment

ASSET NAME: CATCHMENT- SURROUNDING HILLSIDES

ASSET DESCRIPTION: Wetland catchment possesses very rich biodiversity of flora and fauna the southern slopes are steep whereas the northern side is characterized by gentle slopes, hills that surround the lake from its northern and southern sides are covered with sub-tropical forests.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **High**	With high rainfall and increased intensity of rainfall with a shorter duration the degraded catchment area will be having high soil erosion	Increased gap-filling afforestation in the catchment.	**High[1]**	**Medium[2]**	**Medium**
		Obstruct the natural flow of water entering the lake through different measures.	**High[3]**	**Medium[4]**	**Medium**
		Construction of siltation dams and settling pools in the catchment area wherever possible.	**Medium[5]**	**Medium[6]**	**Medium**
		In areas of high/steep slopes and poor and thin soil layers, soil erosion control is difficult. The design can consider bio-engineering methods for gully erosion control, drainage lines that carry runoff and sediment flow.	**High[7]**	**Medium[8]**	**Medium**
	With the degradation of catchment area having less forest cover the water holding capacity will decrease hence leading to higher water runoff of the hill slopes	Improving the management of land and water through soil conservation measures. Afforestation in catchment forests and around so to impact microclimate	**High[9]**	**Medium[10]**	**Medium**

[1] It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity, plantation of mixed-species will assist erosion control in drawdown area.
[2] The impact will be partially avoided and its effectiveness will grow with time as trees mature and adaptation will take time.
[3] It involves various measures such as Bunding, Terracing, Leveling, Diversion drains, Contour Trenches, Stone Walls, Retaining Walls, Check Dams, and Silt Traps. Very little R&D is needed as the Watershed Department undertakes such activities on regular basis. It will be implemented by the Watershed Department with effective coordination of the Forest Department.
[4] The impact will be partially avoided and its effectiveness will depend on the combined effect of the number of activities undertaken under it, its adaptation will be immediate,
[5] It will be implemented by the Watershed department with effective coordination of the Forest Department. It involves higher costs but the Watershed Department has a budget allocated and labour costs can be covered through MGNREGA. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by improving the catchment area, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise they can become counterproductive.
[6] The impact will be partially avoided and will need regular maintenance for it to function effectively.
[7] They may have different forms such as drainage channels, gullies, connecting to natural/artificial waterways leading to streams or rivers downstream. It will be done by the Watershed Department with effective coordination with the Forest department
[8] The impact will be partially avoided and its adaptation will be immediate.
[9] Afforestation in catchment forests can positively influence the microclimate, which can enhance the resilience to climate variability to some extent locally. Planted forests work as carbon sinks on degraded soils thereby mitigating the climate change impact. The activity will be done by the forest department as this is a regular activity and they do it every year. The budget may not be a problem as they can integrate this activity in their work schedule for which a budget may be already allocated.
[10] The impact will be partially avoided.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Watershed management activities, terracing in the slope areas where maximum runoff happen, terracing is already done in Himachal mostly for agricultural fields.	**High**[11]	**Medium**[12]	**Medium**
	With more days of high-intensity rainfall, there will be more chances of flooding.	Repair of existing damaged protective structures and reinforce existing structures through structural protection measures. And undertaking measures for flow retardation by detention/retention basins, Flow deviation by the construction of deviation channel, Acceleration of outflow through pipelines.	**High**[13]	**Medium**[14]	**Medium**
		Non-structural measures: flood warning and forecasting systems.	**Medium**[15]	**Medium**[16]	**Medium**
Increase in temperature during Winter (Jan-Feb) - **High**	The growth of certain plants that need winter chill or lower temperature may get affected.	Increasing the local species having a high leaf area index (LAI) to make forests cooler.	**High**[17]	**Medium**[18]	**Medium**
	Species pertaining to milder or warmer temperatures may alter the biodiversity of the forest.	Increase tree species diversity to reduce risk.	**High**[19]	**Medium**[20]	**Medium**

[11] This can be undertaken by the forest department, but the activity is highly time-consuming and labour intensive. Terracing by reducing the slope gradient helps in cases where rainfall is increasing or intensifying (by reducing slope gradient and the hydrological connectivity), and where rainfall is decreasing (by increasing infiltration and reducing runoff).

[12] The impact will be partially avoided. The impact of the adaptation will be for a long time to come

[13] It will be jointly undertaken by the forest department, the Civil Works Department and the watershed department the cost of repair works will be low but construction of flow retardation, deviation & acceleration outflow pipeline structures cost of implementation of these strictures will be quite high.

[14] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[15] It will be undertaken by local the meteorological department. The local meteorological department already has day to day inputs from the state and the central meteorological department so the cost of broadcasting the information will be low.

[16] The impact on life and property will be partially avoided. It can be easily and immediately adopted. The impact of the adaptation will be for a long time to come.

[17] This can be undertaken by the forest department. Dense canopies, with high LAIs, can block over 95% of visible light from reaching the Earth's surface (Bonan, 2008), and this should keep the air and soil beneath the canopy cool during the day. In temperate forests, this effect plays an important role in protecting temperature sensitive species from the impacts of climate change (De Frenne et al., 2013; Stephen et al., 2015).

[18] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[19] Increase the tree species diversity by investing in those species which are local most resilient to change and therefore most likely to persist. It will be implemented by the Forest Department, the existing budget would be sufficient to carry out this activity. Plantation of mixed species will assist in maintaining a healthy biodiversity.

[20] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during Summer (Mar-May) - **High**	It may lead to dryness and increased mortality in forests	Plantation of species that will be more resilient to high temperatures. Increase tree species diversity to reduce risk. Deep-rooted trees can withstand long duration heatwaves.	**High**[21]	**Medium**[22]	**Medium**
	Change in biodiversity	Investing in those species which are local most resilient to change and therefore most likely to persist.	**High**[23]	**Medium**[24]	**Medium**
	Negatively impact plants that are vulnerable to heat stress	Emphasis on techniques that increase soil moisture.	**Medium**[25]	**Medium**[26]	**Medium**
		Pre-treatment of seedlings	**High**[27]	**Medium**[28]	**Medium**
		Genetic engineering of trees	**Medium**[29]	**Medium**[30]	**Medium**
	More fire incidents leading to more tree mortality	Selecting species that are future climatic suitable and low fire-prone.	**High**[31]	**Medium**[32]	**Medium**
	The plants unable to cope with the heat will vanish or shift to higher and cooler altitudes	Investing in those species which are local more resilient to change and therefore most likely to persist. Increasing the local species having a high leaf area index (LAI). Increase the forest canopy cover.	**High**[33]	**Medium**[34]	**Medium**

[21] Plantation of species with deeper roots, these trees can maintain their cooling function even during long-lasting heatwaves (Teuling et al., 2010, Zaitchik et al., 2006). It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity.

[22] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[23] A healthy forest in the catchment and good green cover outside can alter the temperature at local scale which can ultimately lead to lesser impact on biodiversity "At the local scale, forests can remain much cooler during daytime due to shade and the role of evaporation and transpiration in reducing sensible heat" (Hesslerová et al., 2013, Maes et al., 2011, Pokorný et al., 2010). It will be implemented by the forest Department, existing budget would be sufficient to carry out this activity.

[24] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[25] It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity. Although the direct effects of high temperature on trees can be severe, extreme high-temperature events under conditions of high soil moisture are relatively rare (Teskey et al., 2014).

[26] The impact will be partially avoided. the impact of the adaptation will be for a long time to come.

[27] It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity also the cost will be very low. Tolerance of heat stress can be conferred by prior exposure to moderately high temperatures. For instance, pretreatment of seedlings. (Teskey et al., 2014).

[28] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[29] The activity to be done by the Forest Department with institutional support from research institutes, the cost will be high and will be a time-consuming activity as it will involve R&D. Genetic engineering of trees has great potential to provide rapid improvement in heat and drought tolerance of trees by utilizing introduced genes gained from research on other plant types, which is much farther along than it is in trees (Harfouche et al. 2011; Teskey et al., 2014).

[30] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[31] The activity will be done by the Forest Department. It will be a low cost as it is very much aligned to their core activity.

[32] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[33] These activities will be done by the Forest Department. These activities are very much aligned to their core activities and no extra budget is needed. The department should consider current conditions for regeneration (planting or natural regeneration) as well as expected conditions 50 years from now. Forest canopies buffer climate extremes and promote microclimates that may function as refugee for understory species under changing climate.

[34] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during Post-Monsoon (Oct-Dec) - **High**	Alter the bio-diversity as it will impact the tree growth or survival of the plants needing winter chill.	Plantation of species that will be more resilient to high temperature, Increase tree species diversity to reduce risk.	**High**[35]	**Medium**[36]	**Medium**
	Impact the plant growth.	No adaptation measures are required[37].			
	It may have a positive impact on plant growth but at the same time may alter the biodiversity.	Investing in those species which are local most resilient to change.	**High**[37]	**Medium**[38]	**Medium**
EXTREME EVENTS					
Flood - **Very High**	With floods, the degraded catchment area will be having high soil erosion.	Afforestation along the flood channels led to the retention of rainwater and reduces the discharge. Live Check Dams/Vegetative Barriers, contour bunding and plantation, Mechanical Measures, Terracing, Leveling, Diversion drains, Trenches, Stone Walls, Retaining Walls. Gap filling afforestation, flow retardation: reservoirs (detention/retention basins) wherever needed and site-specific.	**High**[40]	**Medium**[41]	**Medium**
Drought - **Very High**	With the drought, the temperature will increase and will lead to higher thermo-evaporation.	Plantation will increase groundwater.	**High**[42]	**Medium**[43]	**Medium**

[35] Increase the tree species diversity by investing in species that are local most resilient to change making the forest more future climate-ready and therefore most likely to persist. It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity plantation of mixed species.

[36] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[37] It will have a positive impact on some species at a high temperature. And moisture usually induces growth.

[38] Increase the tree species diversity by Investing in species that are the local most resilient to change making the forest more future climate-ready and therefore most likely to persist. It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity plantation of mixed species.

[39] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[40] Ecological Soft Solutions such as restoration of and management of flooding zones, afforestation along the flood channels which led to the retention of rainwater and reduces the discharge. The afforestation will be undertaken by Forest Department & water conservation activities by the Watershed Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department.

[41] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[42] The afforestation will be undertaken by the Forest Department with no extra budget and the department has the required capability.

[43] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Less rainfall or no rainfall will lead to less percolation of water leading to low recharge of catchment areas.	Infiltration and groundwater recharge can be facilitated by trees. Groundwater recharge through Gully Plug, Contour Bund, Dug-well Recharge, Percolation Tank, Check Dam, Recharge Shaft.	High[44]	Medium[45]	Medium
	Though the water in the lake is not directly dependent on rainfall but on springs inside the lake but with less rainfall and less water recharge the springs/ aquifers will also dry up leading to decreased lake water levels.	Water conservation measures in the catchment as given above. Increased tree cover will lead to better groundwater recharge.	High[46]	Medium[47]	Medium
	Drought will lead to higher mortality of flora.	Plantation of drought-resistant trees with respect to climate climatic suitability. Soil conservation measures to increase soil moisture and retention to ward of negative impacts. Watershed management activities to the increased underground water table.	High[48]	Medium[49]	Medium
	With the drought, the catchment area will have more plant mortality so there will lesser food availability.	Plantation of local drought-resistant and palatable varieties other Adaptation measures same as above. Soil and water conservation measures are already defined above.	High[50]	Medium[51]	Medium
	Decrease in the population of some forest species.	New plantations selection based on future climate change projections and site suitability.	High[52]	High[53]	Medium

[44] By evapotranspiring, trees recharge atmospheric moisture, contributing to rainfall locally and in distant locations. Cooling is explicitly embedded in the capacity of trees to capture and redistribute the sun's energy (Pokorný et al., 2010). The afforestation will be undertaken by the Forest Department & water conservation activities by the Watershed Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department.

[45] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[46] Water conservation activities will be undertaken by the Watershed Department with effective coordination with the Forest Department. Very little R&D as the Watershed Department undertakes such activities on regular basis.

[47] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[48] Factors that should be considered when selecting species include growth rate, site requirements, climatic suitability, genetic variability, wildlife value, biological diversity and erosion control.

[49] Ecological Soft Solutions such as restoration of and management of flooding zones. Afforestation along the flood channels lead to the retention of rainwater and reduces discharge. The afforestation will be undertaken by the Forest Department and water conservation activities will be undertaken by the Watershed Department. While afforestation activities do not require an extra budget, watershed activities will be costly.

[50] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[51] The palatable varieties will serve as fodder for wild animals during drought conditions and also will enhance resilience capacity towards climate change in general conditions. Plantation will be undertaken by the Forest Department in collaboration with the wildlife department and afforestation activities with no extra budget may be needed. Social forestry can be liked to increase the green cover outside the catchment area and few villages falling under the catchment with help of communities.

[52] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[53] Factors that should be considered when selecting species include growth rate, site requirements, climatic suitability, genetic variability, wildlife value, biological diversity and erosion control.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Vanishing of species unable to cope with heat stress and lesser water availability.	Altering the microclimate by enhancing forest canopy cover within the catchment and outside to shield it from regional climate change.	High[54]	High[55]	Medium
Fire - **Very High**	Increase in Forest Stand Mortality	Landscape flammability can be reduced through species selection.	High[56]	High[57]	Medium
		Integrating all activities and actors related to fire management, such as prevention, preparedness, suppression and restoration, into one coordinated process of fire management, planning and implementation.	High[58]	Medium[59]	Medium
		Plan fuel breaks (e.g., roads, bulldozer lines, thinned areas, or bodies of water) to slow the spread of wildfire and protect areas of high concern or value.	High[60]	High[61]	Medium
		Setting up of forest fire monitoring and early monitoring system in areas known for a recurrent forest fire.	High[62]	Medium[63]	Medium
	Loss of wildlife	Establish firebreaks or fire lines to stop fire so that it gives wildlife some time to escape.	High[64]	Medium[65]	Medium

[54] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[55] It is well known that trees serve to buffer understory environments from climate extremes (Chen et al. 1999, Suggitt et al. 2011, von Arx et al. 2013, Frey et al. 2016). Buffering may promote microclimates that function as micro-refugia, locations that provide favourable local climate conditions amidst unfavourable regional conditions (Dobrowski 2011, Keppel et al. 2012, Hylander et al. 2015, McLaughlin et al. 2017).

[56] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[57] One way of managing landscape flammability is through species selection (Cathelijne, 2011). Strategies to increase resilience include creating multi-aged stands and favouring more drought and fire-tolerant trees in existing stands. Such activities will be taken by the Forest Department. It will be a process with a long-term strategy to execute.

[58] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[59] Such activities will be taken by the Forest Department with the active participation of the Fire Department empowering the Forest Department with training's and latest strategies and equipment's it will be a process with a long-term strategy to execute. Forest Department has an annual budget for fire-related activities.

[60] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[61] It will be taken by the Forest Department. The department has all the capacity to execute it without R&D. Also no budget is required as the Forest Department has an annual budget for fire-related activities.

[62] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[63] Early warning teams can be set up by the Forest Department in close coordination with communities. It can be set up for early detection and dousing of fire before it turns into a massive disastrous event. It may involve budget allocation if community members are involved.

[64] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[65] Firebreaks can be quite successful in stopping the spread of a creeping fire, a fire line is defined as a narrow portion of a control line from which inflammable materials have been removed by scraping or digging down to mineral soil. It will be taken by the Forest Department without additional R&D and budget.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Food availability will be affected	Maximizing the local broadleaf deciduous palatable Species in the forest.	**High**[66]	**Medium**[67]	**Medium**
	Loss of soil moisture	Soil conservation measures to increase soil moisture and retention to ward of negative impacts. Watershed management activities to increase underground water table.	**High**[68]	**Medium**[69]	**Medium**
	Negative impact on groundwater recharge capacity	Setting up of multi-aged tree stands which are drought and fire-tolerant in existing stands. For example, oak species.	**High**[70]	**Medium**[71]	**Medium**
		As an immediate aftereffect of massive fire is increased runoff and erosion impacting groundwater watershed activities can make catchment more resilient to groundwater impacts of fire.	**High**[72]	**Medium**[73]	**Medium**

[66] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[67] Forest fires seldom occur in the deciduous broad-leaved forests of the temperate zones (www.britannica.com/science/forestry/Fire-prevention-and-control). The palatable varieties will serve as fodder for wild animals during drought conditions and also will enhance resilience capacity towards climate change in general conditions. plantation will be undertaken by the Forest Department in collaboration with the wildlife department and afforestation activities exclusively by the Forest Department with no extra budget may be needed, the social forestry can be liked to increase the green cover outside the catchment area and few villages falling under the catchment with help of communities.

[68] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[69] Watershed management activities to increase underground water table & increase soil moisture and retention to ward of negative impacts will be undertaken by the Watershed Department in close coordination with the forest department. Afforestation will be undertaken by the Forest Department. It has all the capacity to execute it and no R&D will be required. Also, no budget is required as the Forest Department has an annual budget for fire-related activities.

[70] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[71] Strategies to increase resilience include creating multi-aged stands and favouring more drought and fire tolerant trees in existing stands. Systematic afforestation will be undertaken by the Forest Department.

[72] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

[73] Watershed activities including gully plug, contour bund, dug-well recharge, percolation tank, check dam, recharge shaft will not only increase percolation and recharge increasing the water table but also help in controlling erosion after forest fires.

[74] The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

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

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

Photo credit: JoblessStudios.GIZ

Annex 3.2 - Adaptation Planning Matrix for Habitats

ASSET NAME: SHALLOW WATER ON THE SIDES PROVIDING A HABITAT FOR BIRDS AND DRY BANK AREAS PROVIDING NESTING GROUND FOR TURTLE

ASSET DESCRIPTION: These are the two distinct habitats present in the Renuka Wetland. One is the Shallow water habitat for migratory birds created by the silt brought down by the seasonal streams and the other is the dry bank areas providing nesting ground for turtles.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **Very High**	Initially, the silt brought down to the lake proved beneficial for the migratory birds but it is going to reverse now as excessive rainfall will lead to excessive siltation filling up of shallow water and eventually turning them into dry banks faster which is not needed at all.	Increased afforestation in the catchment areas which are vulnerable to erosion.	**High**[1]	**Medium**[2]	**Medium**
		Stopping the natural flow of silted water from entering the lake through different measures.	**High**[3]	**Medium**[4]	**Medium**
		Construction of siltation dams and settling pools in the catchment area wherever possible.	**Medium**[5]	**Medium**[6]	**Medium**
		In areas of high/steep slopes and poor and thin soil layers, soil erosion control is difficult. The design can consider bio-engineering methods for gully erosion control, drainage lines that carry runoff and sediment flow.	**High**[7]	**Medium**[8]	**Medium**
		Improving the management of land and water through soil and water conservation measures.	**High**[9]	**Medium**[10]	**Medium**

[1] It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity, plantation of mixed-species will assist erosion control in drawdown area.

[2] The impact will be partially avoided and its effectiveness will grow with time as trees mature and adaptation will take time.

[3] It involves various measures such as bunding, terracing, levelling, diversion drains, contour trenches, stone walls, retaining walls, check dams, silt traps. Very little R&D is needed as the Watershed Department undertakes such activities on regular basis. It will be implemented by the Watershed Department with effective coordination of the Forest Department.

[4] The impact will be partially avoided and its effectiveness will depend on the combined effect of the number of activities undertaken under it, its adaptation will be immediate.

[5] It will be implemented by the Watershed department with effective coordination of the Forest Department. It involves higher costs but the Watershed Department has a budget allocated and labour costs can be covered Through MGNREGA. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by improving the catchment area, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise they can become counterproductive.

[6] The impact will be partially avoided and will need regular maintenance for it to function effectively.

[7] They may have different forms such as drainage channels, gullies, connecting to natural/artificial waterways leading to streams or rivers downstream. It will be done by the Watershed Department with effective coordination with the Forest Department.

[8] The impact will be partially avoided and its adaptation will be immediate.

[9] Afforestation in catchment forests can positively influence the microclimate, which can enhance the resilience to climate variability to some extent locally. Planted forests work as carbon sinks on degraded soils thereby mitigating the climate change impact. The activity will be done by the Forest Department as this is a regular activity and they do it every year. The budget may not be a problem as they can integrate this activity in their work schedule for which budget may be already allocated.

[10] The impact will be partially avoided.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Increase in silt trapping mechanisms before it reaches the lake through bags made of biodegradable geotextile.	**High**[11]	**Medium**[12]	**Medium**
	Since the lake size is small so is its carrying capacity. As eutrophication is high any new sediment load into the lake is silently leading to its death, the area and dry banks will increase but at the cost of narrowing down the habitat for migratory birds and turtles every passing year.	Same measures need to be taken as described above along with de-siltation of the lake by dredging and mechanical removal of accumulated sediments and organic matter.	**High**[13]	**Medium**[14]	**Medium**
	It will lead to a geographical shift in the habitat.	A balance of shallow water habitat for migratory and dry bank areas through various measures and physical help in the creation of habitat and restoration of habitat for birds and nesting ground turtles through soil and water conservation activities.	**High**	**Medium**	**Medium**
	Water level will change only with flooding or flash flooding impacting the nesting area.	Flood management measures, improving and repairing existing damaged protective structures of flooding in catchments, reinforce existing structures through structural protection measures like check dams, block ramps etc. in the catchment. Terracing in the slope areas where maximum runoff happen, terracing is already done in Himachal mostly for agricultural fields.	**High**[15]	**Medium**[16]	**Medium**

[11] The activity will be undertaken by the Forest Department and it will require a budget and also expertise from outside so collaboration with a research institute or other organization dealing with it needs to be established during the initial period of training's and also for the pronouncement of material. The geotextile bags are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice in other forestry drains as it is a straightforward, low maintenance technique at trapping silt.

[12] It will have a partial impact in removing the negative impacts the impact of the adaptation will be for a long time to come.

[13] It will be undertaken by the Wetland Authority in close coordination with the Forest Department, wildlife department, Mandir community, the cost of de-siltation will be huge and the budget needs to be allocated for it separately. Due diligence needs to be undertaken before doing any desilting process and only undertaken under expert supervision. By desilting, the original lake bed is disturbed which may have far-reaching adverse effects on the habitat of species &the performance of the lake, the most visible effect is the increase in percolation rate resulting in heavy seepage losses through the lake bed.

[14] It will directly have a long term positive impact and can remove the impact significantly. The impact of the adaptation will be for a long time to come.

[15] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the flood and irrigation department, it will involve a budget for setting up new flood management structures so that not much flood comes into the lake. it will take some time for this adaptation activity to complete and become operational.

[16] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Flow retardation: reservoirs (detention/retention basins). Flow deviation: construction of deviation channel. Acceleration of outflow: through pipelines. Non-structural measures: flood warning and forecasting systems.	**High**[17]	**Medium**[18]	**Medium**
Increase of temperature during Summer (Mar-May) - **High**	The increase in temperature will dry the filled up silted areas faster turning the lake areas into dry banks.	Tree cover shading the banks can have a cooling impact on the lake also deep-rooted trees can provide cooling through better evapotranspiration and withstand long duration heatwaves. Thus reducing the impact.	**High**[19]	**Medium**[20]	**Medium**
		De-siltation so that periphery has a larger water holding capacity.	**High**[21]	**Medium**[22]	**Medium**
	Excessive temperature will lead to increased evapotranspiration of lake water.	High thermo-evaporation can be reduced by the physical method of evaporation reduction i.e by injection of air bubbles into water (bubble plume).	**High**[23]	**Medium**[24]	**Medium**
		High thermo-evaporation can also be reduced by biological covers (Floating Plants).	**High**[25]	**Medium**[26]	**Medium**
		Reduction in thermo-evaporation losses by windbreakers.	**Medium**[27]	**Medium**[28]	**Medium**

[17] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the flood and irrigation department, it will involve a budget for setting up new flood management structures so that not much flood comes into the lake. It will take some time for this adaptation activity to complete and become operational.

[18] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

[19] With deeper roots, trees can maintain their cooling function even during long-lasting heat waves (Teuling et al., 2010, Zaitchik et al., 2006). The activity will be undertaken by the Forest Department and it will not involve any additional budget.

[20] The activity will be taken by the Forest Department, it will take a long time for this adaptation to bear fruits and it will have an impact for a long time to come.

[21] The activity will be taken by the Wetland Department and it will need extra budget and expertise from outside, the activity will take a long time to complete.

[22] It will mitigate the impact partially but will overcome various other issues ailing the wetland.

[23] It will be implemented by the Wetland Department in coordination with the Forest Department. It is a high-cost activity and a separate budget is required for implementing the adaptation measure immediately. In summer the surface water heats and becomes less dense. Below this surface layer, which is 3 to 4 m deep the water remains cold and dense. Artificial de-stratification will happen when injecting a bubble plume in the cold deep layer. Consequently, the evaporation is reduced by informing temperature gradients over the depth of the storage (Yara et al., 2019).

[24] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[25] It will be implemented by the Wetland Department in coordination with the Forest Department. It is a low-cost activity and not much budget is required for implementing the adaptation measures immediately. Floating aquatic plants such as water lily, small duckweed, great duckweed and water meal can reduce the evaporation of water reservoirs by preventing the connection between air and the boundary layer of water. Studies in Thailand have shown that duckweed can reduce evaporation up to 10% (Yara et al., 2019).

[26] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[27] It will be implemented by the Forest Department, no external budget is required for implementing the adaptation afforestation measure immediately when the forest plantation season starts, the activity will take time to bear fruits. The wind is one of the most important factors that affect the rate of evaporation from water surfaces. Planting trees normal to the direction of windward is an effective method for reducing evaporation losses (Yara et al., 2019).

[28] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	It will directly have an impact on food availability and may lead to a change in the biodiversity of the lake.	External feeding during that time.	High[29]	Medium[30]	Medium
	Cause algal blooms	Lake water movement through aerators or fountains.	High[31]	Medium[32]	Medium
		Application of phosphorous-binding products, which prevent nutrients from stimulating algae growth, in nutrient heavy lakes and ponds.	High[33]	Medium[34]	Medium
TEMPERATURE					
Increase of temperature during Post- Monsson (Oct-Dec) - **High**	With increased temperature during the post-monsoon period will make the banks drier and it will not be possible for turtles to make nests as they are hole nesters hence they will be needing the muddy dry banks for nesting. This will lead to a shift in the nesting and hatching period of turtles.	During dry season nesting areas can be kept by sprinklers to keep nesting area moist.			
	Reduce the active reproductive period of turtles.	Hatching and breeding under captivity as a backup measure if the need arises.	High[35]	Medium[36]	Medium
	Effect on the habitats of migratory bird.	Tree cover shading the banks can have a cooling impact on the lake also deep-rooted trees can provide cooling through better evapotranspiration and withstand long duration heatwaves.	High[37]	Medium[38]	Medium

[29] It will be implemented by the Wetland Department in coordination with the Forest Department, it is a low-cost activity and not much budget is required the adaptation measure can be started immediately. The food can be augmented externally and it will not be an expensive proposition.

[30] It will mitigate the impact partially the impact of the adaptation will be temporary.

[31] The activity will be taken by the Wetland Department and a separate budget will be needed for the activity and it will involve high cost and recurring electricity cost, for installation external expertise will be required It is a onetime cost apart from regular maintenance cost. Aerators increase diffused oxygen in the water and reduce the incidence of algal bloom.

[32] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[33] The activity will be taken by the Wetland Department and a separate budget will be needed for the adaptation activity but the cost will be minimal.

[34] It will mitigate the impact partially the impact of the adaptation will be for a long time to come

[35] It will be implemented by the Wetland Department in coordination with the Wildlife Department. It is a high-cost activity and a separate budget is required for implementing the adaptation measure. It will take time to implement and cannot be started immediately It is an option that needs to be kept open as a backup measure so that the habitat loss does not end in species loss.

[36] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[37] With deeper roots, trees can maintain their cooling function even during long-lasting heat waves (Teuling et al., 2010, Zaitchik et al., 2006). The activity will be undertaken by the Forest Department and it will not involve any additional budget.

[38] The activity will be taken by the Forest Department, it will take a long time for this adaptation to bear fruits and it will have an impact for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Increase invasive grasses.	Early detection and rapid eradication response toward invasive species by Physical removal or hand pulling.	**High**[39]	**Medium**[40]	**Medium**
	Reduced area of the lake due to drying.	De-siltation so that periphery has a larger water holding capacity.	**High**[41]	**Medium**[42]	**Medium**
		Increase in spring water output by treatment of catchments.	**High**[43]	**Medium**[44]	**Medium**
	An increase in weed reducing the quality area of the lake.	Early detection and rapid eradication response toward invasive species by Physical removal or hand pulling.	**High**[45]	**Medium**[46]	**Medium**
EXTREME EVENTS					
Flood - **Very High**	The increased sediment in the lake affecting the shallow water as well as the dry banks leading to the reduction in the size of the lake.	Flood management measures, improving and repairing existing damaged protective structures of flooding in catchments, reinforce existing structures through Structural protection measures like check dams, block ramps etc. in the catchment. Terracing in the slope areas where maximum runoff happen, terracing is already done in Himachal mostly for agricultural fields.	**High**[47]	**Medium**[48]	**Medium**
		Flow retardation: reservoirs (detention/retention basins). Flow deviation: construction of deviation channel. Acceleration of outflow: through pipelines. Non-structural measures: flood warning and forecasting systems.	**High**[49]	**Medium**[50]	**Medium**

[39] The eradication and physical removal will be undertaken by the forest as well as wetland departments, it will not involve any additional budget as it is a cost-effective process.

[40] The impact will be partially avoided and its success will depend on regular monitoring and action which will be a continuous process.

[41] The activity will be taken by the Wetland Department and it will need extra budget and expertise from outside, the activity will take a long time to complete.

[42] It will mitigate the impact partially but will overcome various other issues ailing the wetland.

[43] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves a high cost but the Watershed Department has a budget allocated for such activities. As the Lake water is totally dependent on springs to maintain lake water levels it needs work in catchment various ways are there to increase rainwater percolation and groundwater recharge like Contour Bund, Dug-well Recharge, and Check Dam depending upon the site area these measures can be undertaken.

[44] It will mitigate the impact partially.

[45] The eradication and physical removal will be undertaken by forest as well as wetland departments, it will not involve any additional budget as it is a cost-effective process.

[46] The impact will be partially avoided and its success will depend on regular monitoring and action which will be a continuous process.

[47] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the Flood and Irrigation Department. It will involve a budget for setting up new flood management structures so that not much flood comes into the lake. It will take some time for this adaptation activity to complete and become operational.

[48] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

[49] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the Flood and Irrigation Department. It will involve budget for setting up new flood management structures so that not much flood comes into the lake. It will take some time for this adaptation activity to complete and become operational.

[50] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Drought - **High**	Drought will have a negative impact on habitat. It will have a drastic impact on ground recharge and lake water availability and shallow water areas may dry up.	Infiltration and groundwater recharge can be facilitated by trees. Increased catchment treatment activities like groundwater recharge through Gully Plug, Contour Bund, Dug-well Recharge, Percolation Tank, Check Dam, Recharge Shaft etc. Depending upon the site in the catchment and need.	**High**[51]	**Medium**[52]	**Medium**
	It will lead to increased dry banks.	De-siltation so that periphery has a larger water holding capacity.	**High**[53]	**Medium**[54]	**Medium**
		Increase in spring water output by treatment of catchments.	**High**[55]	**Medium**[56]	**Medium**
		Increase in tree cover in the peripheral area.	**High**[57]	**Medium**[58]	**Medium**
	Shifting of habitat	Tree cover shading the banks can have a cooling impact on the lake also deep-rooted trees can provide cooling through better evapotranspiration and withstand long duration heatwaves.	**High**[59]	**Medium**[60]	**Medium**

[51] By evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant locations. Cooling is explicitly embedded in the capacity of trees to capture and redistribute the sun's energy (Pokorný et al., 2010). The afforestation will be undertaken by the Forest Department and water conservation activities by the Watershed Department in close coordination with the Forest Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department.

[52] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[53] The activity will be taken by the Wetland Department and it will need extra budget and expertise from outside, the activity will take a long time to complete.

[54] It will mitigate the impact partially but will overcome various other issues ailing the wetland.

[55] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high cost but the watershed department has budget allocated for such activities. As the lake water is totally dependent on springs so as to maintain lake water levels it needs work in catchment various ways are there to increase rain water percolation and ground water recharge like contour bund, dug-well recharge, check dam depending upon the site area these measures can be undertaken.

[56] It will mitigate the impact partially.

[57] It will be undertaken by the Forest Department, no extra budget is needed for the activity as the department has all the resources and budget for such activities.

[58] It will mitigate the impact partially.

[59] With deeper roots, trees can maintain their cooling function even during long-lasting heat waves (Teuling et al., 2010, Zaitchik et al., 2006). The activity will be undertaken by the Forest Department and it will not involve any additional budget.

[60] The activity will be taken by the Forest Department, it will take a long time for this adaptation to bear fruits and it will have an impact for a long time to come.

Annex 3.2.1 - 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: JoblessStudios.GIZ

Annex 3.3 - Adaptation Planning Matrix for Aquatic Grasses

ASSET NAME: AQUATIC GRASSES PROVIDING FOOD FOR WATER BIRDS AND OTHER AQUATIC SPECIES

ASSET DESCRIPTION: Aquatic grasses are a critical part of the ecosystem; they provide food and habitat for various aquatic species and birds. They also help keep the water clear and healthy by absorbing nutrients, trapping sediments, reducing erosion and adding oxygen.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **High**	Increased turbidity. Reduction in compensation depth, below which light intensity is insufficient to sustain photosynthesis.	Streambank erosion control measures: streambank stabilization measure - gabion method, vegetated geo-grid method, vegetative riprap, stone riprap, pilings with wire or geotextile fencings etc. so depending upon the suitability of the area these methods can be used.	High[1]	Medium[2]	Medium
		Construction of drainage line and diversion which carry runoff and sediment flow.	High[3]	Medium[4]	Medium
		Increase in silt trapping mechanisms before it reaches the lake through bags made of biodegradable geotextile.	High[5]	Medium[6]	Medium
		Construction of siltation dams and settling pools in the catchment area wherever possible.	High[7]	Medium[8]	Medium
		Increased gap-filling Afforestation in the catchment particularly. Afforestation along the flood channels leads to retention of rainwater and reduces discharge.	High[9]	Medium[10]	Medium

[1] The purpose is to stop runoff sediments before it enters the lake ecosystem various methods can be used for controlling stream bank erosion. It will not only stop sedimentation and runoff in the upper reaches but will also help in increasing the groundwater level. The activity will be undertaken by the Watershed Department in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[2] It will directly have a long term positive impact and can remove the impact significantly. the impact of the adaptation will be for a long time to come.

[3] The activity may have different forms such as drainage channels, natural/artificial waterways, so that silted water even before reaching the lake gets diverted. The activity will be undertaken by the Watershed Department, agriculture department(if only they can channelize the mineral-rich water to fields) in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[4] It will have a partial impact and the adaptation will be for a long time to come.

[5] The activity will be undertaken by the Forest Department and it will require a budget and also expertise from outside so collaboration with research institutes or other organizations dealing with it needs to establish during an initial period of training's and also for the pronouncement of material. The geotextile bags are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice in other forestry drains as it is a straightforward, low maintenance technique at trapping silt.

[6] It will have a partial impact and the adaptation will be for a long time to come.

[7] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high labour costs but the Watershed Department has a budget allocated for such activities, and labour costs can be covered Through the MGNREGA Scheme. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by improving the catchment area, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise they can become counterproductive.

[8] The impact will be partially avoided and will need regular maintenance for it to function effectively.

[9] The afforestation will be undertaken by the Forest Department and water conservation activities by the Watershed Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department, the adaptation will take time to bear fruits, the adaptation will have more impact as trees mature. Afforestation along the flood channels will lead to retention of rainwater and reduces discharge.

[10] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	Decrease in growth/production of aquatic grasses as silt load increases during this period	All the above measures will help in increasing the growth and production impacted by increased silt.	**High**	**Medium**	**Medium**
Increase in temperature during winter (Jan-Feb) - **High**	Increased winter temperature leads to an increase in productivity but it may also induce new or invasive plants.	Early detection and rapid eradication response toward invasive species by physical removal or hand pulling.	**High**[11]	**Medium**[12]	**Medium**
TEMPERATURE					
Increase of temperature during Summer (Mar-May) - **High**	An increase in the growth of aquatic plants, but may also induce new or invasive plants.	Early detection and rapid eradication response toward invasive species by physical removal or hand pulling.	**High**[13]	**Medium**[14]	**Medium**
	Warmer summer leads to increased incidences of algal bloom.	Lake water movement through aerators or fountains.	**High**[15]	**Medium**[16]	**Medium**
		Lake water movement through aerators or fountains. Application of phosphorous-binding products, which prevent nutrients from stimulating algae growth, in nutrient heavy lakes and ponds.	**High**[17]	**Medium**[18]	**Medium**
	It may lead to an acceleration in drying up of the lake periphery thereby leading to low output.	De-siltation so that periphery has a larger water holding capacity.	**High**[19]	**Medium**[20]	**Medium**

[11] The eradication and physical removal will be undertaken by forest as well as wetland departments, it will not involve any additional budget as it is a cost-effective process.

[12] The impact will be partially avoided and its success will depend on regular monitoring & action which will be a continuous process.

[13] The eradication and physical removal will be undertaken by forest as well as wetland departments, it will not involve any additional budget as it is a cost-effective process.

[14] The impact will be partially avoided and its success will depend on regular monitoring and action which will be a continuous process.

[15] The activity will be taken by the wetland department and a separate budget will be needed for the activity and it will involve high cost and recurring electricity cost, for installation external expertise will be required It is a one-time cost apart from regular maintenance cost. Aerators increase diffused oxygen in the water and reduce the incidence of algal bloom.

[16] It will partially mitigate the impact and the adaptation will be for a long time to come.

[17] The activity will be taken by the Wetland Authority and a separate budget will be needed for the adaptation activity but the cost will be minimal.

[18] It will partially mitigate the impact and the adaptation will be for a long time to come.

[19] The activity will be taken by the Wetland Authority and it will need extra budget and expertise from outside, the activity will take a long time to complete.

[20] It will mitigate the impact partially but will overcome various other issues ailing the wetland.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
		Increase in spring water output by treatment of catchments.	High[21]	Medium[22]	Medium
		Increase in tree cover in the peripheral area.	High[23]	Medium[24]	Medium
EXTREME EVENTS					
Flash Flooding - **High**	It will have a negative impact it will lead to increased turbidity Reduction in compensation depth, below which light intensity is insufficient to sustain photosynthesis.	Streambank erosion control measures: streambank stabilization measure - gabion method, vegetated geo-grid method, vegetative riprap, stone riprap, pilings with wire or geotextile fencings etc. so depending upon the suitability of the area these methods can be used.	High[25]	Medium[26]	Medium
		Construction of drainage line and diversion which carry runoff and sediment flow.	High[27]	Medium[28]	Medium
		Increase in silt trapping mechanisms before it reaches the lake through Bags made of biodegradable geotextile.	High[29]	Medium[30]	Medium
		Construction of siltation dams and settling pools in the catchment area wherever possible.	High[31]	Medium[32]	Medium

[21] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high cost but the Watershed Department has a budget allocated for such activities. As the lake water is totally dependent on springs so as to maintain lake water levels it needs work in catchment various ways are there to increase rainwater percolation and groundwater recharge including contour bund, dug-well recharge, check dam depending upon the site area these measures can be undertaken.

[22] It will mitigate the impact partially.

[23] It will be undertaken by the Forest Department, no extra budget is needed for the activity as the Forest Department has all the resources and budget for such activities.

[24] It will mitigate the impact partially.

[25] The purpose is to stop runoff sediments before it enters the lake ecosystem various methods can be used for controlling stream bank erosion. It will not only stop sedimentation and runoff in the upper reaches but will also help in increasing the groundwater level. The activity will be undertaken by the Watershed Department in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[26] It will directly have a long term positive impact and can remove the impact significantly. The impact of the adaptation will be for a long time to come.

[27] The activity may have different forms such as drainage channels, natural/artificial waterways, so that silted water even before reaching the lake gets diverted. The activity will be undertaken by the Watershed Department, agriculture department (if only they can channelize the mineral-rich water to fields) in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[28] It will have a partial impact and the adaptation will be for a long time to come.

[29] The activity will be undertaken by the Forest Department and it will require a budget and also expertise from outside so collaboration with research institutes or other organizations dealing with it needs to establish during an initial period of training's and also for the pronouncement of material. The geotextile bags are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice in other forestry drains as it is a straightforward, low maintenance technique at trapping silt.

[30] It will have a partial impact and the adaptation will be for a long time to come.

[31] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high labour costs but the Watershed Department has a budget allocated for such activities, and labour costs can be covered. Through MGNREGA Scheme. Siltation and settling pools are immediate measures that can be carried out to enhance the lake ecosystem by improving the catchment area, but these measures are site-sensitive and need proper site identification particularly in hill areas otherwise they can become counterproductive.

[32] The impact will be partially avoided and will need regular maintenance for it to function effectively.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
		Increased gap-filling afforestation in the catchment particularly. Afforestation along the flood channels leads to retention of rainwater and reduces discharge.	**High**[33]	**Medium**[34]	**Medium**
	Decrease in growth/ production of aquatic grasses as silt load increases during this period.	All the above measures will help in increasing the growth and production impacted by increased silt.	**High**	**Medium**	**Medium**
	Runoff from catchment areas transports nutrients and sediments into lake ecosystems. It may impact the population of aquatic organisms.	lake water movement through aerators or fountains so as to increase dissolved oxygen as turbidity increases water temperature as suspended particles absorb sunlight and resulting in increased water temperature and decrease dissolved oxygen.	**High**[35]	**Medium**[36]	**Medium**
Drought - **High**	Since spring recharge are dependent on catchment recharge so any drought will have an impact if it is for a prolonged period impacting catchment recharge.	Infiltration and groundwater recharge can be facilitated by trees. Increased catchment treatment activities like groundwater recharge through gully plug, contour bund, dug-well recharge, percolation tank, check dam, recharge shaft etc. Depending upon the site in the catchment and need.	**High**[37]	**Medium**[38]	**Medium**
	Droughts may lead to heat stress.	Emphasis on techniques that increase soil moisture.	**High**[39]	**Medium**[40]	**Medium**

[33] The afforestation will be undertaken by the Forest Department and water conservation activities by the Watershed Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department, the adaptation will take time to bear fruits, the adaptation will have more impact as trees mature. Afforestation along the flood channels will lead to retention of rainwater and reduces discharge.

[34] The impact will be partially avoided. The impact of the adaptation will be for a long time to come

[35] The activity will be taken by the wetland department and a separate budget will be needed for the activity and it will involve high cost and recurring electricity cost, for installation external expertise will be required It is a one time cost apart from regular maintenance cost. Aerators increase diffused oxygen in the water and reduce the incidence of algal bloom.

[36] It will partially mitigate the impact and the adaptation will be for a long time to come

[37] By evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant locations. Cooling is explicitly embedded in the capacity of trees to capture and redistribute the sun's energy (Pokorný et al., 2010). The afforestation will be undertaken by the Forest Department and water conservation activities by the Watershed Department in close coordination with the Forest Department, while afforestation activities no extra budget may be needed but watershed activities will be costly and will require allocation by the Watershed Department.

[38] The impact will be partially avoided the impact of the adaptation will be for a long time to come.

[39] It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity. Although the direct effects of high temperature on trees can be severe, extreme high-temperature events under conditions of high soil moisture are relatively rare (Robert Teskey et al., 2014).

[40] The impact will be partially avoided. The impact of the adaptation will be for a long time to come..

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
		Pre-treatment of seedlings.	High[41]	Medium[42]	Medium
		Genetic engineering of trees.	High[43]	Medium[44]	Medium

Photo credit: JoblessStudios.GIZ

41 It will be implemented by the Forest Department, existing budget would be sufficient to carry out this activity also the cost will be very low. "Tolerance of heat stress can be conferred by prior exposure to moderately high temperatures. For instance, pretreatment of seedlings" (Robert Teskey et al., 2014).

42 The impact will be partially avoided the impact of the adaptation will be for a long time to come.

43 The activity to be undertaken by the Forest Department with institutional support from research institutes, the cost will be high and will be a time-consuming activity as it will involve R&D. Genetic engineering of trees has great potential to provide rapid improvement in heat and drought tolerance of trees by utilizing introduced genes gained from research on other plant types, which is much farther along than it is in trees (Harfouche et al., 2011, Robert Teskey et al., 2014).

44 The impact will be partially avoided. The impact of the adaptation will be for a long time to come.

Annex 5.3.1 - 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

Photo credit: JoblessStudios.GIZ

Annex 3.4 - Adaptation Planning Matrix for Golden Mahseer

ASSET NAME: GOLDEN MAHSEER

ASSET DESCRIPTION: Golden Mahseer, *Tor putitora* Hamilton, one of the largest freshwater fish of the Indian sub-continent, Golden Mahseer is listed as endangered on the IUCN Red List. The species have suffered severe population decline in much of their distribution range and are now considered threatened. Mahseer (Tor) fish species are critical across the Indian Himalayan biodiversity hotspot; however, multiple human stressors compounded by climate change have significantly depleted their populations over recent decades.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **Very High**	May lead to lesser space availability for fishes due to increased silt flow impacting its natural habitat.	De-siltation of the lake by dredging and mechanical removal of Accumulated Sediments.	**High[1]**	**Medium[2]**	**Medium**
		Increase in silt trapping mechanisms before it reaches the lake through gags made of biodegradable geotextile.	**High[3]**	**Medium[4]**	**Medium**
		Construction of drainage line and diversion which carry runoff and sediment flow. They may have different forms such as drainage channels, natural/artificial waterways, so that silted water before reaching the lake gets diverted	**High[5]**	**Medium[6]**	**Medium**
		Streambank erosion control measures: • Stream Bank Stabilization - Gabion Method • Vegetated Geo-Grid Method • Iowa Vanes • Vegetative Riprap	**High[7]**	**Medium[8]**	**Medium**

[1] It will be undertaken by the Wetland Authority in close coordination with the Forest Department, the Wildlife Department, and the Mandir community, the cost of de-siltation will be huge and a separate budget needs to be allocated for it. Due diligence needs to be undertaken before doing any desilting process and only undertaken under expert supervision. Due diligence needs to be taken before doing any desilting process. By desilting, the original lake bed is disturbed which may have far-reaching adverse effects on the habitat of species & performance of the lake. The most visible effect is the increase in percolation rate resulting in heavy seepage losses.

[2] It will directly have a long term positive impact and can remove the impact significantly. If a de-siltation process is completed it will go a long way to help in overcoming the impact.

[3] The activity will be undertaken by the Forest Department and it will require a budget and also expertise from outside or collaboration with research institutes or other organizations dealing with it needs to establish during an initial period of training's and also for the pronouncement of material. The geotextile bags are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice in other forestry drains as it is a straightforward, low maintenance technique at trapping silt. The adaptation measure can be adopted straightforward.

[4] It will have a partial effect in removing the impact, the adaptation measure may need replacement with new bags in future.

[5] The activity will be undertaken by the Forest Department with collaboration or expertise from the Watershed Department, (agriculture department can be roped in if only they can channelize the mineral-rich water to fields) may require a budget and work can be taken immediately but to make it functional it will take some time as civil works need to be undertaken, it will need a budget, both the departments have provisions and allocated budget for such activities. The activity may have different forms such as drainage channels, natural/artificial waterways, so that silted water even before reaching the lake gets diverted.

[6] It will have a partial effect in removing the impact, the adaptation measure will last for a long time and in between, it may need maintenance.

[7] It will be implemented by the Forest Department with expertise from the Watershed Department, the activity will require civil work and setting up of structures and it will take some time before it becomes functional. To stop runoff sediments before it enters the lake ecosystem various methods can be used for controlling stream bank erosion.

[8] It will have a partial effect in removing the impact, the adaptation measure will last for a long time and in between, it may need maintenance.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		• Stone Riprap • Pilings with Wire or Geotextile Fencings • Dormant Post Plantings • Coconut Fiber Rolls Method • Branch Packing Method • Live Fascine Method so depending upon the suitability these methods can be used.			
	It will have an impact on its natural food availability.	Alternative feed from outside can be given to the fishes during this period by tourists but only after its standardization and approval by the fisheries department.	**High**[9]	**Medium**[10]	**Medium**
	May impact its breeding as shallow water may be highly silted.	Breeding of Mahseer in a hatchery, developments of breeding and culture techniques along with hatchery management practices as the means for conservation, if such need arises.	**High**[11]	**Medium**[12]	**Medium**
	It may also impact shallow water during the spawning period and may fill it with silt leading to the killing of eggs and fingerlings.	Improving the management of land and water through soil conservation measures. Afforestation in catchment forests to reduce runoff. Terracing in the slope areas where maximum runoff happens, terracing is already done in Himachal mostly for agricultural fields. Construction of silt drainage line and diversion. Streambank erosion control measures.	**High**[13]	**Medium**[14]	**Medium**

[9] It will be undertaken by the Fisheries Department, giving external food, it is viable and cost-effective and can be started immediately, standardization of external food to be given by tourists who usually feed fish also needs to be done by the Fisheries Department.

[10] It will have a partial effect in removing the impact, the adaptation measure has to be undertaken till the food availability situation improves.

[11] The activity will be undertaken by the fisheries department, a high cost will be involved to start a hatchery, and will take time for this adaptation activity. “Breeding of Mahseer in a hatchery, developments of breeding and culture techniques along with hatchery management practices as the means for conservation” (Debajit Sarma, et al., 2018).

[12] It will have a partial effect in removing the impact, the adaptation measure will last for a long time once setup is established.

[13] The activity will be undertaken by the Forest Department with collaboration or expertise from the Watershed Department, may require a budget and work can be taken immediately but to make it functional it will take some time as civil works need to be undertaken, it will need a budget, both the departments have provisions and allocated budget for such activities.

[14] It will have a partial effect in removing the impact, the adaptation measure will last for a long time once setup is established.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) - **Very High**	The change will alter the surface water temperature which in turn may directly impact its breeding as fish prefers to breed in colder waters.	Increasing the local species having a high leaf area index (LAI) to make forests and surroundings around the lake cooler.	**High**[15]	**Medium**[16]	**Medium**
		Increased aeration to increase dissolved oxygen as water temperature increases the dissolved oxygen decreases also increased temperature leads to higher metabolic activity and increased demand for dissolved oxygen.	**High**[17]	**Medium**[18]	**Medium**
		Increased plantations in and around Renuka to impact microclimate.	**High**	**Medium**	**Medium**
		Tree cover shading the banks can have a cooling impact on the lake also deep-rooted trees can provide cooling through better evapotranspiration and withstand long duration heatwaves.	**High**[19]	**Medium**[20]	**Medium**
EXTREME EVENTS					
Flood - **High**	As the intensity of rain has increased over the years and with it flash flooding, it brings a very high load of silt and it has already a very high impact, prime reason of lake dying and destroying the large fish habitat.	Flood management measures, improving and repairing existing damaged protective structures of flooding in catchments, reinforce existing structures through structural protection measures like check dams, block ramps etc. In the catchment. erracing in the slope areas where maximum runoff happen, terracing is already done in Himachal mostly for agricultural fields.	**High**[21]	**Medium**[22]	**Medium**

[15] The activity will be undertaken by the Forest Department, they have all the required expertise to carry out this activity, and it will take time to bear fruits. Dense canopies, with high LAIs, can block over 95% of visible light from reaching the Earth's surface (Bonan, 2008), and this should keep the air and soil beneath the canopy cool during the day. In temperate forests, this effect plays a major role in protecting temperature-sensitive species from the impacts of climate change (De Frenne et al., 2013).

[16] It will have a partial effect in removing the impact, the adaptation measure will take a long time till it bears fruits but once established it will last for a long time.

[17] Increased water temperature also leads to lower dissolved oxygen increased variation with mechanical means will increase dissolved oxygen. The activity will be undertaken by the wetland department, it will involve budget and cost of setup may be high and it may need regular maintenance.

[18] It will have a partial effect in removing the impact, the adaptation measure can be installed and operationalised quickly and once established it will stay for a long time.

[19] With deeper roots, trees can maintain their cooling function even during long-lasting heat waves (Teuling et al., 2010, Zaitchik et al., 2006). The activity will be undertaken by the Forest Department and it will not involve any additional budget.

[20] The activity will be taken by the Forest Department, it will take a long time for this adaptation to bear fruits and it will have an impact for a long time to come.

[21] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the flood and irrigation department, it will involve a budget for setting up new flood management structures so that not much flood comes into the lake. It will take some time for this adaptation activity to complete and become operational.

[22] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Flash floods impact fertilized eggs and the shallow habitat	Flow retardation: reservoirs (detention / retention basins). Flow deviation: construction of deviation channel. Acceleration of outflow: through pipelines. Non-structural measures: Flood warning and forecasting systems.	**High**[23]	**Medium**[24]	**Medium**
Drought - **High**	Drought conditions always negatively impact fish leading to higher mortality	Water conservation measures in the catchment as the Lake water is totally dependent on springs so as to maintain lake water levels it needs work in the catchment and it may include groundwater recharge through Gully Plug, Contour Bund, Dug-well Recharge, Percolation Tank, Check Dam/Cement Plug/Nala Bund, and Recharge Shaft.	**High**[25]	**Medium**[26]	**Medium**
	It will alter or reduce the natural food availability	External feeding during that time frame	**High**[27]	**Medium**[28]	**Medium**
Fire - **High**	Not much impact on fish directly but fires in the catchment can increase erosion and runoff leading to low percolation and drying of the soil thereby impacting the future ability for groundwater recharge and lake water levels	As an immediate aftereffect of massive fire is increased runoff and erosion impacting groundwater percolation on groundwater recharge through Gully Plug, Contour Bund, Dug-well Recharge, Percolation Tank, Check Dam, Recharge Shaft activities can make forests more resilient to groundwater impacts of fire.	**High**[29]	**Medium**[30]	**Medium**

[23] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the flood and irrigation department, it will involve a budget for setting up new flood management structures so that not much flood comes into the lake. It will take some time for this adaptation activity to complete and become operational.

[24] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

[25] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and it will involve a budget for setting up structures. It will take some time for this adaptation activity to complete and become operational.

[26] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

[27] The food can be augmented externally and it will not be an expensive proposition.

[28] It will mitigate the impact partially, and it is a temporary adaptation that will last till food availability in the lake is available.

[29] Watershed management activities to increase underground water table and increase soil moisture and retention to ward of negative impacts. For example, oak species. Afforestation will be undertaken by the Forest Department. The department has all the capacity to execute it and no R&D will be required. Also, no budget is required as the Forest Department has an annual budget for fire-related activities. The watershed activities will be undertaken by the Watershed Department in close coordination with the Forest Department.

[30] It will mitigate the impact partially, the impact of the adaptation will be for a long time to come.

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: JoblessStudios.GIZ

Annex 3.5 - Adaptation Planning Matrix for Turtles

ASSET NAME: TURTLES

ASSET DESCRIPTION: The *Batagur* and *Nilssonia* spp. turtles found in the deepwater of Renuka Wetland with terrestrial nesting sites and are the most threatened freshwater turtles in India. The Red-Crowned Roof Turtle, *Batagur kachuga,* is listed as Critically Endangered on the IUCN Red List of Threatened Species. *Nilssonnia gangetica* and *Nilssonia hurum* are both listed as Endangered. The Red-crowned Roof Turtle is listed as schedule 1 of the Indian Wildlife Protection Act 1972 and is listed on Appendix II of the Convention on International Trade in Endangered Species (CITES).

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **Very High**	With increased rainfall or increased intensity of rainfall, the soil erosion will increase leading to increased siltation deposition and eutrophication which will further lead to the loss of habitat.	De-siltation of the lake by dredging and mechanical removal of accumulated sediments and organic matter.	**High[1]**	**Medium[2]**	**Medium**
		Increase in silt trapping mechanisms before it reaches the lake through bags made of biodegradable geotextile.	**High[3]**	**Medium[4]**	**Medium**
		Construction of Drainage line and diversion which carry runoff and sediment flow.	**High[5]**	**Medium[6]**	**Medium**
		Streambank erosion control measures. Stream Bank Stabilization measures include Gabion Method, Vegetated Geo-Grid Method, Vegetative Riprap, Stone Riprap, Pilings with Wire or Geotextile Fencings etc., depending upon the suitability of the area these methods can be used.	**High[7]**	**Medium[8]**	**Medium**

[1] It will be undertaken by the Wetland Authority in close coordination with the forest department, the Wildlife Department, and the Mandir community, the cost of de-siltation will be huge and a budget needs to be allocated for it separately. Due diligence needs to be undertaken before doing any desilting process and only undertaken under expert supervision. By desilting, the original lake bed is disturbed which may have far-reaching adverse effects on the habitat of species and the performance of the lake, most visible effect is the increase in percolation rate resulting in heavy seepage losses through the lake bed.

[2] It will directly have a long term positive impact and can remove the impact significantly. The impact of the adaptation will be for a long time to come.

[3] The activity will be undertaken by the Forest Department and it will require a budget and also expertise from outside so collaboration with research institutes or other organizations dealing with it needs to establish during an initial period of training's and also for the pronouncement of material. The geotextile bags are designed to decompose over time, leaving an earthen bank to attenuate water and prevent silt and other fine materials from entering the main channel. The method can be used as best practice in other forestry drains as it is a straightforward, low maintenance technique at trapping silt.

[4] It will have a partial impact in removing the negative impacts. The impact of the adaptation will be for a long time to come.

[5] The activity may have different forms such as drainage channels, natural/artificial waterways, so that silted water even before reaching the lake gets diverted. The activity will be undertaken by the Watershed Department, Agriculture Department (if only they can channelize the mineral-rich water to fields) in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[6] It will have a partial impact. The impact of the adaptation will be for a long time to come.

[7] The purpose is to stop runoff sediments before it enters the lake ecosystem various methods can be used for controlling stream bank erosion. It will not only stop sedimentation and runoff in upper reaches but will also help in increasing the groundwater level. The activity will be undertaken by the Watershed Department in coordination with the Forest Department and it may require a budget and work can be taken immediately after budget allocation.

[8] It will have a partial impact and the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	With increased eutrophication and less dissolved oxygen, food availability will also decrease	Although Turtle eats a wide variety of food from aquatic plants to fish still alternative feed from outside can be given if necessary during unfavourable conditions. Aeration can be increased by installing aerators to increase diffused oxygen in the water, which in turn helps to improve the overall aquatic ecosystem.	High[9]	Medium[10]	Medium
	Decrease in the population of turtles	The Turtles in Renuka are protected from poaching and other external anthropogenic threats due to religious reasons but there needs to be a backup plan which involves hatching and breeding at another location also to preserve the gene pool as habitat is under threat.	High[11]	Medium[12]	Medium
Decrease of rainfall during the dry season (Oct-May) - **High**	Decrease in underground spring discharge.	Water conservation measures in the catchment. Increased tree cover will lead to better groundwater recharge.	High[13]	Medium[14]	Medium
	It can have a double blow because the outer periphery is already filled up with silt, with decreased rainfall the low spring discharge may lead to quick-drying out into a dry surface.	De-siltation so that periphery has larger water holding capacity.	High[15]	Medium[16]	Medium
		Increase in spring water output by treatment of catchments.	High[17]	Medium[18]	Medium
		Increase in tree cover in the peripheral area.	High[19]	Medium[20]	Medium

[9] The activity will be taken by the Fisheries Department. It is viable and cost-effective and can be started immediately but standardization of external food needs to be done by the aquatic wildlife experts. Aerators increase diffused oxygen in the water, which in turn helps to improve the overall aquatic ecosystem, It is a one-time cost apart from regular maintenance cost and can be effective to increase dissolved oxygen levels and this part of The activity will be taken by the Wetland Authority.

[10] It will partially mitigate the impact and the adaptation will be for a long time to come.

[11] Experimental hatching and breeding at another location can be undertaken so that backup is there if the population of the species decline as habitat is under threat. The activity can be undertaken by the Wildlife Department and the Wetland Authority in close association with the research organization. It will involve a huge cost to establish them in a captive or other open habitat and involves some sort of research and development so the budget needs to be allocated for it separately.

[12] It will not mitigate the problem but will lead to the development contingency plan.

[13] Afforestation will be implemented by the Forest Department, the catchment treatment activities involving civil work will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high cost but the Watershed Department has a budget allocated for such activities, As the Lake water is totally dependent on springs so as to maintain lake water levels it needs work in catchment various ways are there to increase rainwater percolation and groundwater recharge including contour bund, dug-well recharge, check dam depending upon the site area these measures can be undertaken.

[14] It will mitigate the impact partially.

[15] The activity will be taken by the Wetland Authority and it will need extra budget and expertise from outside, the activity will take a long time to complete.

[16] It will mitigate the impact partially but will overcome various other issues ailing the wetland.

[17] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high cost but the Watershed Department has a budget allocated for such activities, As the Lake water is totally dependent on springs so as to maintain lake water levels it needs work in catchment various ways are there to increase rainwater percolation and groundwater recharge including contour bund, dug-well recharge, check dam depending upon the site area these measures can be undertaken.

[18] It will mitigate the impact partially but the adaptation measure will last for a long time.

[19] It will be undertaken by the Forest Department, no extra budget is needed for the activity as the Forest Department has all the resources and budget for such activities.

[20] It will mitigate the impact partially but the adaptation measure will last for a long time but it will take some time for this adaptation measure to bear fruits.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	That may lead to loss of food or a decrease in food availability.	External feeding during such times.	High[21]	Medium[22]	Medium
EXTREME EVENTS					
Flood - **Very High**	Loss of habitat area suitable for nesting	De-siltation of the lake by dredging and mechanical removal of accumulated sediments and organic matter.	High[23]	Medium[24]	Medium
	Lesser nests in the succeeding year	Nesting area protection, repair and restoration leading to increasing available nesting habitat.	High[25]	Medium[26]	Medium
Drought - **Very High**	Higher thermo- evaporation leading to drying of the lake.	High thermo-evaporation can be reduced by a physical method of evaporation reduction i.e by injection of air bubbles into water (bubble plume).	High[27]	Medium[28]	Medium
		High thermo-evaporation can also be reduced by biological covers (Floating Plants).	High[29]	Medium[30]	Medium
		Reduction in thermo-evaporation losses by windbreakers.	Medium[31]	Medium[32]	Medium

[21] It will be done by the Wildlife Department, it is viable and cost-effective and will not need much budget and can be started immediately.

[22] It will mitigate the impact partially, the adaptation measure is temporary and will last for an unfavourable period only.

[23] The activity can be undertaken by the Forest Department with technical expertise from the Watershed Department and may be in close cooperation with the flood and irrigation department, it will involve a budget for setting up new flood management structures so that not much flood comes into the lake, and also improving and repairing existing damaged protective structures of flooding in catchments, reinforce existing structures through structural protection measures like check dams, block ramps etc. in the catchment.

[24] It will mitigate the impact partially and the adaptation will be for a long time to come.

[25] It is viable and cost-effective and the Wildlife Department can undertake this activity it hardly requires any specialized budget and can be started immediately.

[26] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[27] It will be implemented by the Wetland Authority in coordination with the Forest Department, it is a high-cost activity and a separate budget is required for the adaptation, the measure can be started immediately. In summer the surface water heats and becomes less dense. Below this surface layer, which is 3 to 4 m deep the water remains cold and dense. Artificial de-stratification will happen when injecting a bubble plume in the cold deep layer. Consequently, the evaporation is reduced by uniforming temperature gradients over the depth of the storage (Yara et al., 2019).

[28] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

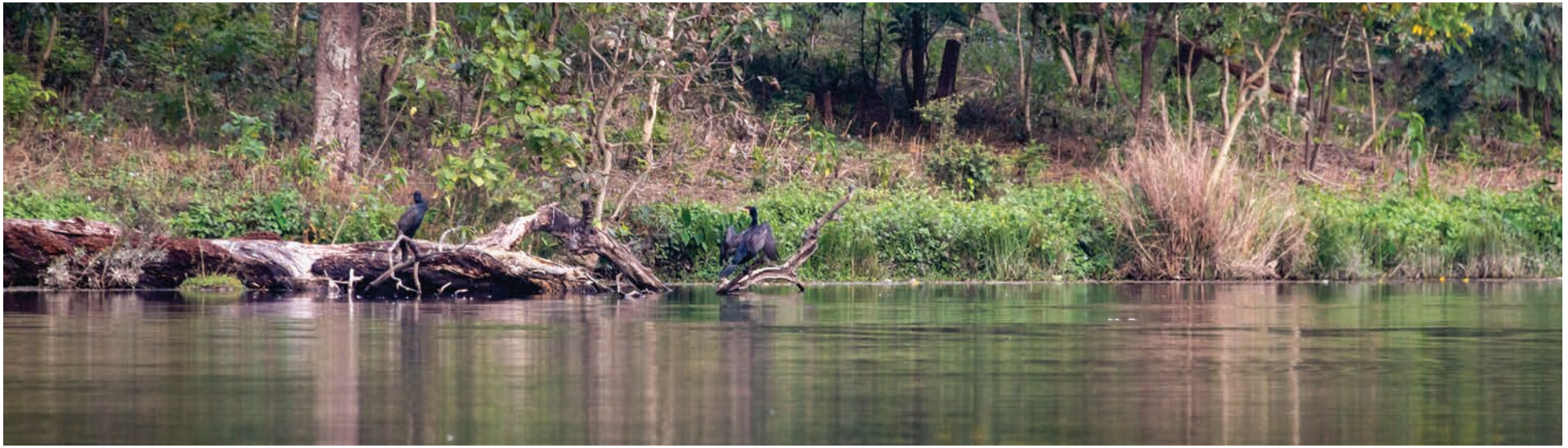
[29] It will be implemented by the Wetland Authority in coordination with the Forest Department, it is a low-cost activity and not much budget is required the adaptation measure can be started immediately., Floating aquatic plants such as water lily, small duckweed, great duckweed and watermeal can reduce the evaporation of water reservoirs by preventing the connection between air and the boundary layer of water. Studies in Thailand have shown that duckweed can reduce evaporation up to 10% (Yara et al., 2019).

[30] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[31] It will be implemented by the Forest Department, no external budget is required the adaptation afforestation measure can be started immediately when the forest plantation season starts, the activity will take time to bear fruits. The wind is one of the most important factors that affect the rate of evaporation from water surfaces. Planting trees normal to the direction of windward is an effective method for reducing evaporation losses (Yara et al., 2019).

[32] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Low recharge of catchment areas leading to decreased water output of internal springs.	Water conservation measures in the catchment.	High[33]	Medium[34]	Medium
		Increased tree cover will lead to better groundwater recharge.	High[35]	Medium[36]	Medium
	Decrease in the population of turtles	Same adaptation measure as above.			
	Lesser food availability	External feeding during that time.	High[37]	Medium[38]	Medium
	Decrease in the population of turtles	Hatching and breeding under captivity as a backup measure.	High[39]	Medium[40]	Medium



[33] It will be implemented by the Watershed Department with effective coordination of the Forest Department. It involves high cost but the Watershed Department has a budget allocated for such activities. As the Lake water is totally dependent on springs so as to maintain lake water levels, it needs work in catchment various ways are there to increase rainwater percolation and groundwater recharge including contour bund, dug-well recharge, check dam depending upon the site area these measures can be undertaken.

[34] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[35] It will be implemented by the Forest Department, and not much budget is required the adaptation measure can be started immediately. Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge. Precipitation filtered through forested catchments delivers purified ground and surface water (Calder, 2005, Neary et al., 2009).

[36] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[37] It will be implemented by the Wetland Authority in coordination with the Forest Department, it is a low-cost activity and not much budget is required the adaptation measure can be started immediately. The food can be augmented externally and it will not be an expensive proposition.

[38] It will mitigate the impact partially. The impact of the adaptation will be temporary.

[39] It will be implemented by the Wetland Authority in coordination with the Wildlife Department. It is a high-cost activity and a separate budget is required for the adaptation measure. It will take time to implement and cant' be started immediately It is an option that needs to be kept open as a backup measure so that the habitat loss doesn't end in species loss.

[40] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

Annex 3.5.1 - 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: JoblessStudios.GIZ

Annex 3.6 - Adaptation Planning Matrix for Recreation, Tourism, Religious Tourism

ASSET NAME: RECREATION, TOURISM, RELIGIOUS TOURISM

ASSET DESCRIPTION: Lake, Religious tourism and yearly Fair is a big attraction. Wildlife sanctuary, Mini zoo, Boating are the other tourist attractions.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **Very High**	Less attractive due to high humidity	Expanding scientific research-based sustainable tourism by roping in various universities and research institutes to send budding researchers for research as this is the time when most universities are closed for summer vacations.	High[1]	Medium[2]	Medium
		Out-of-box solutions such as increased activities to promote it as a destination for the nature trail and wildlife-based tourism like organizing camps and tour packages during this season by the Tourism Department in coordination with the Forest Department.	High[3]	Medium[4]	Medium
	It will impact daily tourism and recreational activities negatively.	Development and promotion of eco-tourism sites around Renuka for nature enthusiasts and wilderness seekers.	High[5]	Medium[6]	Medium
		Weather-based early warning updates.	High[7]	Medium[8]	Medium
		Increased focus on road safety measures and engineering measures to be undertaken to reduce risks at vulnerable points.	High[9]	Medium[10]	Medium

[1] This activity will be promoted by the Tourism Department in association with the Forest Department, the activity needs a promotional budget as well as liasoning with institutes and research-based organizations and it may take some time for it to start giving results. As the destination has a wildlife sanctuary as well as a lake, it can be promoted as good research and education-based tourist destination during passive tourism season. It will immensely help Renuka as very limited research studies have been undertaken there and it has so much to offer at one place as it is a unique site having a wildlife sanctuary, a wetland, freshwater springs dotted around, a mini zoo and also is also a Ramsar site of international importance.

[2] It will mitigate the impact partially. The impact of the adaptation will take time to mature and bear fruits but its impact will be for a long time to come.

[3] Nature Walks and Trails are a way to create awareness among tourists about the importance of conservation and the role that nature plays in ensuring a healthy ecosystem & opportunities for observing and learning about the flora and fauna.

[4] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[5] This activity will be taken and promoted by the Tourism Department in association with the Forest Department, the activity needs a promotional budget. The adaptation will take time to mature and bear fruits.

[6] It will mitigate the impact partially the impact of the adaptation will be for a long time to come.

[7] The activity will be undertaken by the meteorological department and in coordination with the Tourism Department. the local Early warning systems can be used to reduce the risk by giving alerts to the public, providing them enough time to prepare for response. It can be started immediately.

[8] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[9] The risk due to landslides is a major concern in hilly terrains and landslides are often associated with disasters the impacts it is often underestimated. The activity will be undertaken by a government agency responsible for roads i.e. Public Works Department (PWD), this will be an ongoing activity and it will need a budget and implementing agency has enough funds every year for such activities.

[10] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come but need of regular maintenance will be there.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Well laid and maintained roads so that tourists have a pleasurable road trip experience[11].	**High[12]**	**Medium**	**Medium**
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) - **Very High**	It will have a negative impact as increased temperature coupled with high humidity will be not good for recreational and tourist activities.	The same activities undertaken during the monsoon will need to be repeated here.	**High[13]**	**Medium[14]**	**Medium**
EXTREME EVENTS					
Flood - **High**	It will have a negative impact as flash floods will trigger landslides and soil erosion leading to road blockage. It will lead to less tourist influx and will impact the tourist industry.	Insurance can be an important factor in reducing the financial risk for individuals. Proper insurance can considerably mitigate the effects that extreme events have on them and can prevent them from being ruined.	**High[15]**	**Medium[16]**	**Medium**
		Comprehensive contingency plans to respond to floods should be prepared in due time and maintained in an operational state.	**High[17]**	**Medium[18]**	**Medium**
Drought - **Very High**	It will have a negative impact leading to less tourist influx which will impact the livelihood of tourist operators.	Diversifying the local businesses that are focused on tourism and recreation activities outside the sensitive Renuka wildlife sanctuary. Promotion of activities like rock climbing, trekking and cultural tourism which in some way needs sunny weather for a pleasurable experience outside can be started to reduce the impacts of droughts and make it a sustainable tourist destination.	**High[19]**	**Medium[20]**	**Medium**

[11] The activity will be undertaken by a government agency responsible for roads i.e. Public Works Department (PWD), this will be an ongoing activity and it will take time, it will need a budget and implementing agency has enough funds every year for such activities. Adverse perception about roads and their safety especially in mountain areas has become a concern for tourists in terms of security and protection and it leads to high recall value when deciding to make it a destination of choice for future or recurrent trips.

[12] It will mitigate the impact. The impact of the adaptation will be for a long time to come but need of regular maintenance will be there.

[13] This activity will be promoted by the Tourism Department in association with the Forest Department, the activity needs a promotional budget as well as liasoning with institutes and research-based organizations and it may take some time for it to start giving results. As the destination has a wildlife sanctuary as well as a lake it can be promoted as good research and education-based tourist.

[14] It will mitigate the impact partially. The impact of the adaptation will take time to mature and bear fruits but its impact will be for a long time to come.

[15] Floods can lead to a high loss reduction to business owners to defend their property against flood damage so to cover losses the insurance is an important adaptation tool. It will be undertaken by the Tourism Department in collaboration with insurance agencies and various community stakeholders. It will not need any budget as stakeholders will pay for their respective insured infrastructure.

[16] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[17] Training's and Regular joint exercises should be done with stakeholders to respond to floods so as to increase response capabilities and preparedness so that there is a very low loss of life and property. The activity will be undertaken by disaster mitigation agencies along with various stakeholders it will not need any additional budget as the agency has enough training resources to prepare the community for various disasters.

[18] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

[19] The Tourism Department in collaboration with government based skill development agencies into various other businesses for advertising tourism outside the sensitive area. This will not only promote tourism but will help in reducing the stress around Renuka lake and catchment as new infrastructure will get developed for tourists for boarding and lodging outside the sensitive area which otherwise is confined to the lake area and somehow impacting it negatively during fair and when tourist rush is there.

[20] It will mitigate the impact partially. The impact of the adaptation will be for a long time to come.

Annex 3.6.1 - 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

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