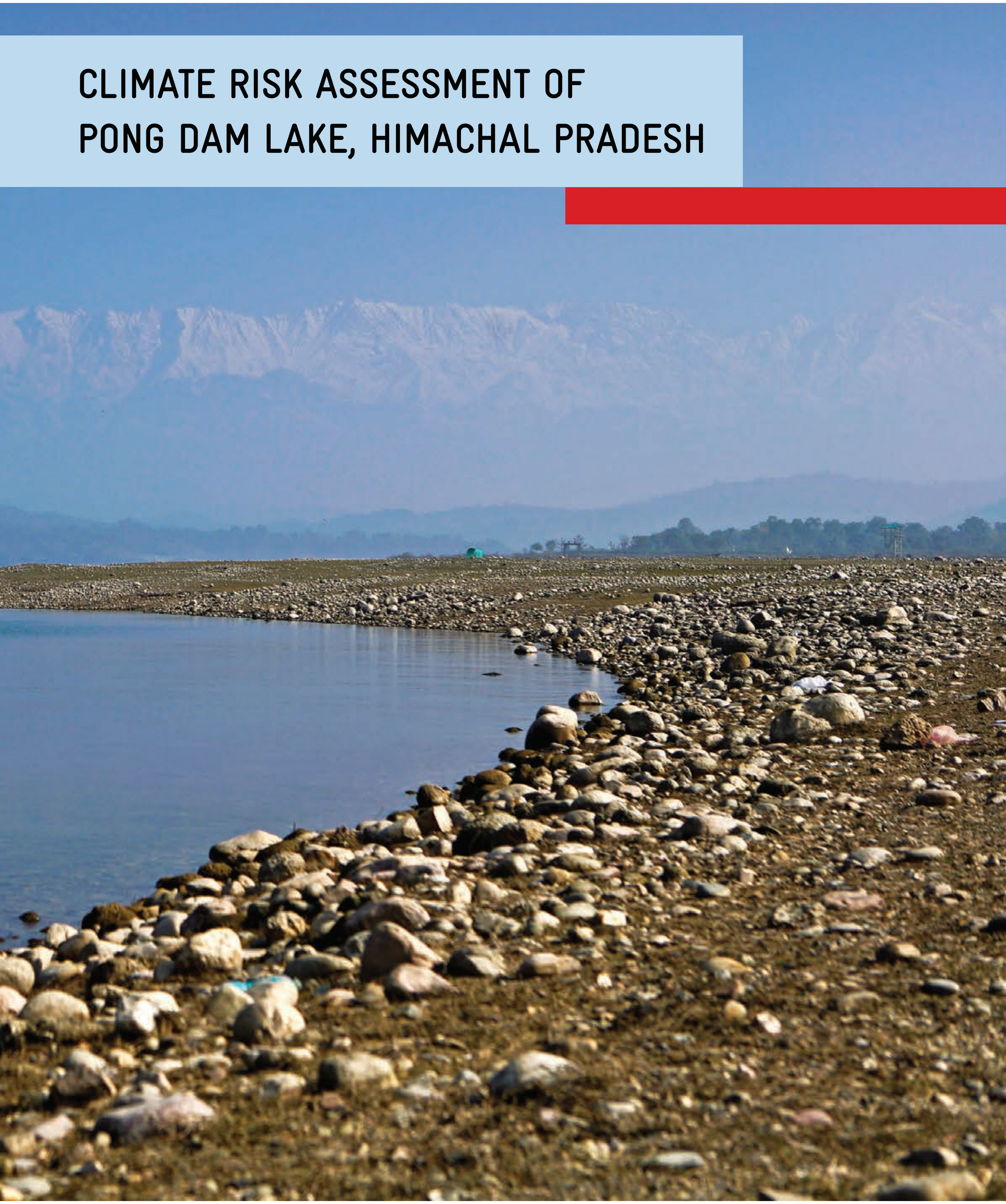
CLIMATE RISK ASSESSMENT OF PONG DAM LAKE, HIMACHAL PRADESH



हिमाचल प्रदेश सरकार

IKI INTERNATIONAL CLIMATE INITIATIVE

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New Delhi, 2023

CLIMATE RISK ASSESSMENT OF PONG DAM LAKE, HIMACHAL PRADESH

icem
Climate Change | Biodiversity
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RCDC

MSSRF
Science for Sustainable Development

DEVELOPMENT OPTION SYSTEM

ABBREVIATIONS AND ACRONYMS

ACF	ASSISTANT CONSERVATOR FOREST
ADB	ASIAN DEVELOPMENT BANK
BBMB	BHAKHRA BEAS MANAGEMENT BOARD
BICAT	BASIN-WISE INTEGRATED CATCHMENT AREA TREATMENT
BOD	BIOLOGICAL OXYGEN DEMAND
CABI	CENTRE FOR AGRICULTURE AND BIOSCIENCE INTERNATIONAL
CAM	CLIMATE CHANGE ADAPTATION AND MITIGATION
CDA	CHILIKA DEVELOPMENT AUTHORITY
CHL	LEAF CHLOROPHYLL
CIFRI	CENTRAL INLAND FISHERIES RESEARCH INSTITUTE
CM5A	COUPLE MODEL VERSION 5
CMIP	COUPLED MODEL INTERCOMPARISON PROJECT
CMIP5	COUPLED MODEL INTERCOMPARISON PROJECT VERSION 5
COD	CHEMICAL OXYGEN DEMAND
COP	CONFERENCE OF THE PARTIES
CORDEX-SA	COORDINATED REGIONAL CLIMATE DOWNSCALING EXPERIMENT SOUTH ASIA
CRA	CLIMATE RISK ASSESSMENT
CSKHPAU	CHAUDHARY SAARWAN KUMAR HIMACHAL PRADESH AGRICULTURE UNIVERSITY
CWC	CENTRAL WATER COMMISSION
DEST	DEPARTMENT OF ENVIRONMENT AND TECHNOLOGY
DFO	DIVISIONAL FOREST OFFICE
DFS-GOPA	DAIMLER FINANCIAL SERVICES INDIA PVT. LTD. – GOPA
DO	DISSOLVED OXYGEN
DRM	DISASTER RISK ASSESSMENT
EDCS	ECO-DEVELOPMENT COMMITTEES
ESZS	ECO-SENSITIVE ZONES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FECCD	FOREST, ENVIRONMENT AND CLIMATE CHANGE DEPARTMENT
FPOS	FARMER PRODUCERS ORGANISATIONS
GDD	GROWING DEGREE DAYS
GENS	THE GLOBAL ENVIRONMENTAL STRATIFICATION
GIS	GEOGRAPHIC INFORMATION SYSTEM
GIZ	DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT GMBH
GLOFS	GLACIAL LAKE OUTBURST FLOODS
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
ICIMOD	INTERNATIONAL CENTRE FOR INTEGRATED MOUNTAIN DEVELOPMENT
IMD	INDIA METEOROLOGICAL DEPARTMENT
INCCA	INDIAN NETWORK ON CLIMATE CHANGE ASSESSMENTS
INRM	INFLUENTIAL NETWORK RELATION MAP
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IPSL-CM5A	INSTITUT PIERRE SIMON LAPLACE – CLIMATE MODEL 5A
IUCN	INTERNATIONAL UNION FOR CONSERVATION OF NATURE
JFMC	JOINT FOREST MANAGEMENT COMMITTEES
LAI	LEAF AREA INDEX
LULC	LAND USE AND LAND COVER
MoEFCC	MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
MoES	MINISTRY OF EARTH SCIENCES
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
NEX	NASA EARTH EXCHANGE
NPCA	NATIONAL PLAN FOR CONSERVATION OF AQUATIC ECOSYSTEMS
NTFPS	NON-TIMBER FOREST PRODUCTS
PLBCS	PONG LAKE BIODIVERSITY CONSERVATION SOCIETY
PMSBY	PRIME MINISTER SURAKHYA BIMA YOJANA
PRDWD	PANCHAYATI RAJ AND DRINKING WATER DEPARTMENT
PRECIS	PROVIDING REGIONAL CLIMATES FOR IMPACTS STUDIES
RAINFOREST CRC	COOPERATIVE RESEARCH CENTRE FOR TROPICAL RAINFOREST ECOLOGY AND MANAGEMENT
RCDC	REGIONAL CENTRE FOR DEVELOPMENT COOPERATION
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
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

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Acknowledgements

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SUMMARY

Wetland systems are highly vulnerable to climate change. As climatic patterns become more extreme, the impacts on wetlands become more pronounced through alterations in temperature, hydrological regimes and increased 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 Pong Dam Lake Ramsar site. The aim is to have the results of this technical and consultative process integrated into the overall management plan to enhance site resilience through effective adaptation to climate change.

PONG DAM LAKE RAMSAR SITE

The reservoir, located at longitude 76˚04'E and latitude 32˚01'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 main crops cultivated in the command area are rice, wheat, maize and cotton. Monsoon rainfall between June and September is a primary source of the water inflow into the reservoir, apart from snow and glacier melt. At Pandoh Dam, upstream of Pong Dam, the snow and glacier melt runoff from the Beas catchment was about 35% of the annual flow for the years 1990–2004 (Kumar et al., 2007).

The Management Plan for Pong Lake 2014–2023 (D.S. Dhadwal, ACF Pong Lake) notes that about 220 bird species belonging to 54 families were recorded (Pandey 1989) (Ramsar site RIS, 2002). Between 2004 and 2011, Dhadwal photographed 426 bird species at the wetland, which is more than 70% of the bird diversity in the whole of Himachal Pradesh. 18 species of snake, 95 species of butterfly and 24 species of mammal were also recorded in the lake area. The most recent HPFD Annual Waterbird census figures show that over 100,000 water birds were counted from over 100 species, of which 60 were migratory. The 2021 figures show a slight decline in these numbers.

METHODOLOGY FOR THE CLIMATE VULNERABILITY ASSESSMENT AT THE PONG DAM LAKE RAMSAR SITE

The climate vulnerability assessment of the Pong Dam Lake Ramsar site was conducted using the Climate Change Adaptation and Mitigation (CAM) method developed by ICEM as a flexible tool and process for climate change adaptation and mitigation planning and implementation tailored specifically to wetlands. 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. The CAM method has three main phases: (i) impact and vulnerability assessment; (ii) adaptation planning; and (iii) implementation and feedback. The GIZ and ICEM team worked with site managers and local stakeholders to apply the CAM method to establish the evidence base for robust and well-informed site management. The method considers four factors in assessing the vulnerability of the target system and its components based on an understanding of the threats posed by climate change: exposure, sensitivity, impact and adaptive capacity.

BASELINE CONDITIONS AT THE PONG DAM LAKE RAMSAR SITE

The target assets considered in this vulnerability assessment include the catchment area, extending to the high elevation glaciers and glacial lakes at the top of the Beas river, and the forested catchment areas of the smaller rivers flowing into the reservoir. The Beas river catchment includes 358 glaciers, with a total area of 768 km^2, and 74 glacial lakes, with a total area of 236 km^2, five of which are considered to be dangerous, carrying a risk of GLOFs. Lower parts of the catchment include agricultural areas with some small urban areas. The degraded parts of the catchment are prone to soil erosion. The Pong Dam hydel and the reservoir are important artificial assets that regulate the release of water for irrigation and water supply in Punjab, Harayana and Rajasthan. The water level in the reservoir rises during the monsoon months from June to September and is drawn down during the dry season. With a dam elevation at 435.86 m above sea level, and the full supply level at 422 masl, the reservoir extends 41.8 km upstream from the dam

and covers a surface of 245 km^2. Pong Reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The seasonal drawdown in the reservoir exposes 180 km^2 of sand and mudflats around the periphery of the reservoir (Pong Dam Management Plan 2014). The key habitats considered in the vulnerability assessment are the migratory bird habitats, consisting of:

- the northeastern shore and deltas of the rivers entering the reservoir where the birds roost
- the shallow water areas where the dabbling ducks feed
- the surrounding terrestrial vegetation and croplands, where the Bar-headed Geese feed

The security of the roosting areas and availability of different food sources are considered important features of the Pong Dam lake Ramsar site that maintain its attractiveness for migratory birds. Species assets considered in the vulnerability assessment include the Bar-headed Geese *(Anser indicus)* and Northern Pintail *(Anas acuta).* Bar-headed Geese breed in high altitude lakes in Central Asia and migrate from their summer breeding grounds to winter in South Asia. Pong Dam is one of their first destinations after crossing the Himalaya. It receives tens of thousands of geese each year. Northern Pintails also breed in the north and migrate to overwinter in the south, including at Pong Dam lake.

The other target species asset is the Golden Mahseer *(Tor putitora),* an endangered fish, which migrates to breed in the colder fast-running waters of the rivers and streams flowing into the reservoir during the monsoon and returns to spend the rest of the year in the reservoir. The species is threatened by habitat degradation, competition from other fish species and overfishing, and in the past decade, its population has declined by 50%.

The ecosystem services provided by the wetland include community-based ecotourism and fishing. There are about 3038 licenced fishers who catch fish as their principal livelihood, with an average catch of 400 tonnes per year at 15 landing centres around the reservoir (CIFRI Assessment Report. 2020 data). The annual fish production is generally linked to the water levels in the reservoir.

CLIMATE CHANGE AT THE PONG DAM LAKE RAMSAR SITE

Projections of precipitation and temperature by 2050 at the Pong Dam lake Ramsar site were modelled by ICEM against a baseline period of 1960–1990, using an ensemble mean method of three selected GCMs, CCSM4, HadGEM2-ES and MIROC-ESM, for the RCP 8.5 scenario.

Precipitation

By the 2050s, the total precipitation is projected to increase by 262.1 mm (17.7%), from 1479.8 mm to 1741.9 mm, during the SW monsoon (June–September). The total precipitation is projected to decrease during the NE monsoon by 12.4 mm (10.8%), in winter by 18.3 mm (10.7%), and in summer by 11.8 mm (5.3%). Those projections are generally consistent with results from a recent climate change assessment for the Pong Basin conducted using CORDEX South Asia RCM.

More significant changes in precipitation, increasing during the SW monsoon and decreasing during other seasons, are projected for immediate upstream zones of the Pong Dam lake.

Temperature

The average maximum temperature is projected to increase significantly by 1.8°C to 3.3°C by 2050. The highest increases are projected for the monsoon seasons at 3.1°C for the SW monsoon (from 24.1°C to 27.2°C) and 3.3°C for the NE monsoon (from 15.6°C to 18.9°C). The winter months (January–February) are projected to be warmer, with an increase in the average maximum temperature of 2.8°C (from 9.6°C to 12.4°C). The average maximum temperature during summer is also projected to increase by 1.8°C, from 23.9°C to 25.7°C. These projections are generally consistent with the CORDEX South Asia RCM assessment. Those increases have very significant implications for the Ramsar site ecosystems.

Extreme events

Heavy and very heavy precipitation days (R10mm and R20mm) are projected to increase in Pong Dam towards the 2050s compared with the baseline period (1960–1990). Very wet days and extremely wet days will increase in the Kangra district, as will consecutive dry days and wet days, high wind events and wind speed during the NE monsoon and in winter.

The increase in precipitation is likely to return as groundwater recharge. Streamflow and groundwater recharge is projected to increase in all districts by 2050.

IMPACT AND VULNERABILITY ASSESSMENTS

Impact and vulnerability assessments were conducted for the six target assets. From a Ramsar site perspective, the key feature of the Pong Dam lake is its ecosystem health and attractiveness for the large numbers of migratory birds visiting each year and the fish species and overall productivity of the reservoir. Without these, the area would be simply another large man-made reservoir, and the focus of the vulnerability assessment would be different – perhaps on the functioning of the hydel plant.

The most important climate change threats to Pong Dam and the reservoir are an increase in rainfall during the monsoon (17.7%) by the 2050s and a more significant increase in immediate upstream areas in the catchment, which will be combined with an increase in frequency and magnitude of flooding and glacial melt and an increased risk of glacial lake outburst flooding. There will be a substantial decrease in rainfall during winter (10.7%), with increasing consecutive days of drought and an increase in the average temperature by 2.8°C, 1.8°C and 3.3°C in winter, the pre-monsoon season and the post-monsoon season, respectively.

The increase in rainfall and flash flooding during the monsoon is likely to increase soil erosion in the catchment and sediment deposition in the reservoir. Sedimentation in the reservoir is already an issue of concern because most of the sediment is deposited in the active storage volumes of the reservoir around the shallow drawdown areas, forming deltas where the khads flow into the reservoir. These are the areas favoured by the roosting and feeding migratory birds. Increased sediment deposition will change the ecological character of these areas, smothering the bed and aquatic vegetation on which the birds feed.

The changes in the hydrology of the reservoir and potential increase in flooding are concerns both to the operators of the hydel plant and the managers of the Ramsar site. Although Pong Dam offers a considerable degree of regulation of the Beas river, the ability of the management of the hydel plant to cope with changes in regular flows and extreme flooding is constrained by the demand for irrigation water and power generation. Filling of the reservoir may occur more rapidly during the monsoon with the future increase in rainfall, meaning that spillways will have to be operated earlier to pass the more frequent floods downstream. In the rest of the year, the hotter temperatures and increased number of drought days will increase the demand for irrigation water, so that drawdown of the reservoir is likely to be more rapid. The changing hydrological patterns of the fill and drawdown of the reservoir will also change the ecological character of the reservoir. It is not known how this will affect the migratory bird habitats, although the fish production is dependent on the period of high-water levels in the reservoir.

The attractiveness of the Pong Dam lake area for migratory birds depends on the safety of the roosting areas for large congregations of water birds and the availability of food sources so they gain strength and recover from their flights over the Himalayas and down south. This assessment does not cover the vulnerability of the birds at their breeding sites in Central Asia, although increasing temperatures in southern destinations may cause larger numbers of migratory birds to overwinter at Pond Dam lake in the future.

The continued provision of adequate food sources for the migratory birds will depend on the ecological and productivity shifts within the aquatic environment, particularly the shallow waters where the dabbling ducks such as the Northern Pintail *(Anas acuta)* feed on aquatic vegetation and invertebrates, and the terrestrial vegetation and crops grown in the drawdown area and surrounding the reservoir, where the Bar-headed Geese *(Anser indicus)* and lapwings feed. The combination of increased temperatures, decreased rainfall and drought during the winter and hot seasons will change the varieties and species best suited to the new conditions, their cropping patterns and productivity, making the provision of adequate food sources uncertain.

Increased reservoir water temperatures throughout the year, but especially during the hot and pre-monsoon seasons, may change the water quality, decreasing the dissolved oxygen content, already a trend. It is possible that the increased surface water temperatures may give rise to the stratification of deeper parts of the reservoir. This will carry an increased risk of overturning bringing anaerobic waters to the surface from the bottom at certain times of the year causing fish mortality, e.g. in autumn when the winds create turbulence. Increased sediment coming down the rivers during the monsoon is also likely to increase turbidity in the reservoir. The changing water quality is likely to affect the fisheries, favouring warm-water species at the expense of colder water species such as the Golden Mahseer *(Tor putitora)* although the increased rainfall during the monsoon may make it easier for the spawning migrations of this species up the rivers and streams.

Summary Vulnerability Assessment matrix for Pong Dam and its assets

Threats	Catchment					Reservoir					Pong Dam Hydel					Migratory bird habitats					Bar Headed Geese and Northern Pintail					Golden Mahseer					Fisheries				
	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	Exp	Sen	Imp	Adc	Vul
Precipitation																																			
Increase of rainfall during Monsoon (Jun–Sep)	H	M	H	H	M	VH	H	VH	M	VH	H	L	M	H	M	VH	M	VH	M	VH	VH	M	VH	M	VH	H	M	H	M	H	H	M	H	H	M
Decrease of rainfall during Winter (Jan-Feb)	H	M	H	M	H	H	M	H	M	H	H	M	H	L	H	H	M	H	M	H	H	M	H	M	H	L	L	L	M	M	H	L	M	M	M
Temperature																																			
Increase of temperature during the hot season/Monsoon (Jun–Sep)	VH	H	VH	L	VH	VH	H	VH	L	VH	VH	H	VH	L	VH	VH	H	VH	L	VH	VH	H	VH	L	VH	H	H	H	L	VH	H	H	H	L	H
Increase of temperature during the cold season (Oct–May)	H	H	H	L	H	M	M	M	L	M	H	H	H	L	H	H	H	H	L	H	H	H	H	L	H	M	M	M	L	M					
Extreme events																																			
Flood	H	M	H	H	M	H	M	H	M	H	H	M	H	H	M	H	H	H	M	H	H	H	H	M	H	H	H	H	M	H	H	M	H	M	H
Flash flooding						L	L	L	H	L						L	L	L	H	L	L	L	L	H	L										
Drought	M	L	M	M	M	H	H	H	M	H	M	L	M	M	M	L	L	L	M	M	L	L	L	M	M	H	H	H	L	H	H	H	H	L	H
Wind	L	L	L	H	L	H	M	H	M	H	L	L	L	H	L	H	M	H	VL	VH	H	M	H	M	H						H	M	H	VL	VH

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

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

ADAPTATION PLANS

Adaptation plans focus on measures to ensure water flows to and through the wetland and the management of water levels in the reservoir, which means balancing the water releases for irrigation and water supply downstream with incoming waters to retain the functioning of the reservoir habitat. Climate change is expected to increase the risk of floods from landslides, glacial melt and glacial lake flooding in the upper catchment, which will require watershed management measures. Soil erosion in the catchment leading to increased sedimentation in the reservoir is already a threat to the wetland habitat, and measures to reduce erosion impacts of increased monsoon rainfall in the catchment will be required, including reforestation where necessary and soil conservation measures and sediment trapping.

Within the reservoir, measures for restoration and protection of the wetland habitats for migratory birds include progressive desilting and maintenance of the shallow water habitat condition and productivity by creating additional habitat diversity, e.g., through small perched wetlands in the drawdown, mounds and depressions. Additional species protection measures may include provision of additional food sources for migratory birds, e.g., by planting specific crops in the drawdown area, designation of protection areas where the migratory birds roost and feed and establishing fish conservation zones within the reservoir and upstream spawning sites.

Reviewing and enforcement of the fishery regulations and licenses will be required, with fishing bans during the spawning season and the use of revenues from the fish catch auctions for restoring degraded fish habitats. Diversification of the regional and community-based tourism on Pong Dam lake is proposed to encourage livelihoods of communities around the Ramsar site, and the development of agricultural insurance for farmers losing crops to migratory birds is to reduce conflict between the farmers and these birds.

RECOMMENDATIONS FOR THE MANAGEMENT OF THE SITE AND STAKEHOLDERS

Feasibility studies and planning will be required to design and implement these different adaptation options, both in the catchment and in the reservoir itself. Research into different aspects of the Pong Dam wetland and into habitat restoration and creation is recommended to strengthen the current knowledge about the site and how it functions. The different Pong Dam Lake stakeholders, especially the Forest Department, Wetland Authority, BBMB, which owns and operates the Pong hydel project, the Fisheries Department, the local communities and fishers need to be involved in the adaptation planning and implementation and in the research and monitoring required. It will be necessary to establish a coordination platform, an adaptation management committee under the Pong Lake Biodiversity Conservation Society (PLBCS), to identify and plan the adaptation measures and integrate them into the existing site management plans and hydel operating rules.

1 INTRODUCTION

1.1 Background

Wetland systems are highly vulnerable to climate change. As climatic patterns become more extreme, there may be pronounced effects on wetlands through alterations in the 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 was commissioned by GIZ India to undertake climate risk assessments and adaptation planning for four Indian Ramsar sites that are the focus of the Technical Cooperation project *Wetlands Management for Biodiversity and Climate Protection,* implemented by the Ministry of Environment, Forest and Climate Change (MoEFCC), in partnership with GIZ. The four Ramsar sites are **Renuka Wetland, Pong Dam Lake, Bhitarkanika Mangroves, and Point Calimere Wildlife and Bird Sanctuary.** These four sites, namely, the upland lakes and reservoirs in Himachal Pradesh and coastal mangrove areas in Odisha and Tamil Nadu, represent two very different 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 **Pong Dam Lake Ramsar site** is one of four linked reports on the four Ramsar sites. This report contains two chapters common to all reports, which are followed by chapters with the specific findings on the Pong Dam Lake Ramsar site.

- **Chapter 1** presents the project background and overall methodology used for climate risk assessments at the four Ramsar sites.
- **Chapter 2** describes the baseline conditions at the Pong Dam Lake Ramsar site,
- **Chapter 3** provides the climate change profile of the site.
- **Chapter 4** synthesises and presents results from vulnerability assessments of the target assets, with the detailed VA matrices annexed.
- **Chapter 5** develops the adaptation plans for the site from the annexed adaptation matrices for the target assets.
- **Chapter 6** provides recommendations for the management of the site and for stakeholder engagement.

1.2 Project aims and objectives

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

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

1.3 Overview of the other three Ramsar sites

1.3.1 Renuka Wetland

The Renuka Wetland ((30˚36'N, 77˚27'E) is located at an altitude of 645 m, in Sirmaur district, of Himachal Pradesh (Figure 1). The wetland comprises a large oblong-shaped lake with a small outlet to an adjoining pond, Parashuram Tal, which ultimately drains into the river Girl through a small channel. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as its breadth and has 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.

The Renuka Wetland Management Action Plan (2013–2022) noted that 103 bird species belonging to 38 families have been identified, with 66 species of resident bird. Renuka is also home to freshwater turtles, and feeding them is one of the tourist attractions. The Renuka Management Plan 2013/14 – 2022/23 identifies the Bengal Red-crowned Roofed Turtle *(Batagur kachuga),* which is classified as Critically Endangered on the IUCN Red List.

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

1.3.2 Bhitarkanika Mangroves

Bhitarkanika Mangroves, located in Odisha State, India, occupies about 65,000 ha on the east coast of India (20˚39'N, 86˚54'E) (Figure 1). It was designated a Ramsar site in 2002. This wildlife sanctuary is one of the finest remaining patches of mangrove forest in the region. The site is visited annually by about 500,000 Olive Ridley sea turtles, 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 *(Crocodylis 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. This area also supports 250,000 inhabitants in 410 villages that are mainly dependent on agriculture, fishing and aquaculture.

1.3.3 Point Calimere Wildlife and Bird Sanctuary

Point Calimere Wildlife Sanctuary (10˚18'N, 79˚51'E), along with the Great Vedaranyam Swamp and the Thalainayar Reserved Forest, was declared a Ramsar site in 2002. The total area of the Point Calimere Wetland Complex is 38,500 ha (Figure 1). The Point Calimere Ramsar site is a mix of salt swamps, mangroves, backwaters, mudflats, grasslands and Tropical Dry Evergreen Forest. About 257 species of bird have been recorded, including vulnerable water bird species such as the Spoon-billed Sandpiper *(Calidris pygmaea)* and Spot-billed Pelican *(Pelecanus philippensis)*[1]*.* The sanctuary serves as the breeding ground or nursery for many commercially important species of fish, as well as for prawns and crabs. Many fishers and farmers are dependent on the wetland for their livelihood. The spread of the invasive exotic plant *Prosopis* spp*,* salinisation of groundwater and changes in the inflow of freshwater are all threats to the wetland habitats and species.

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

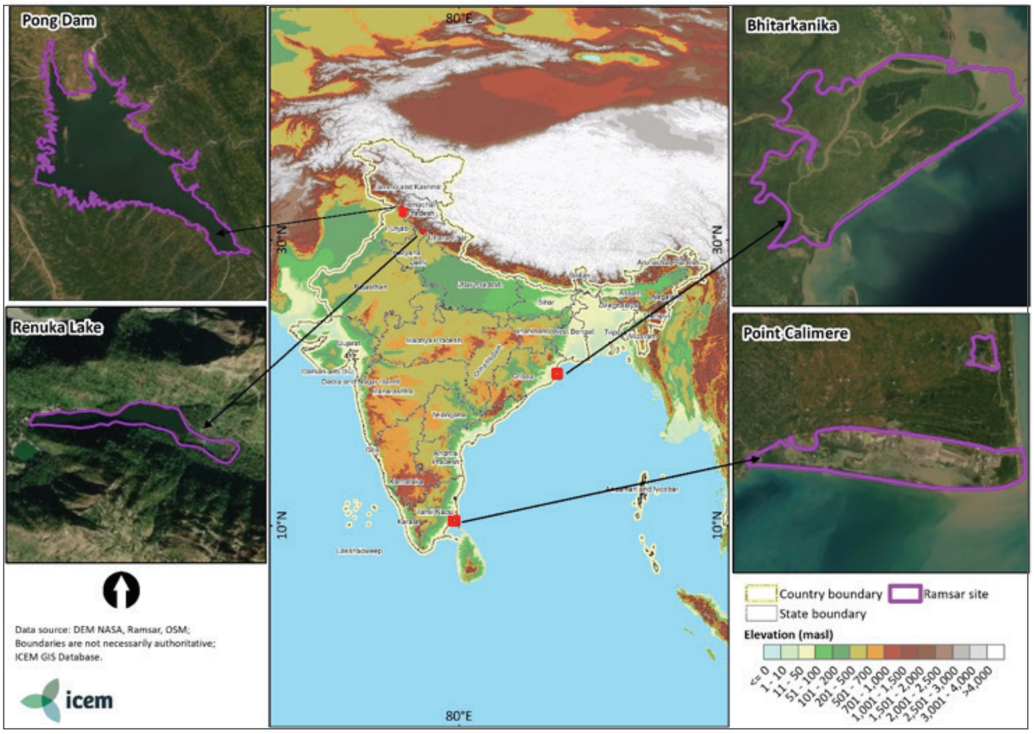


Figure 1 *Locations of the four Ramsar sites targeted for vulnerability assessment and adaptation planning*

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 for climate change adaptation and mitigation planning and implementation. It provides a framework for systematically identifying climate change projections, their impacts and the needed adaptation responses. The CAM method combines a range of assessment and planning tools based on international best practices (Annex 1). In the case of the Ramsar sites in India – the aim is to integrate the CAM tools into the regular Ramsar site management planning cycle. The project tested and demonstrated the methodology at the four Ramsar sites working closely with the site managers and local stakeholders.

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

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

i. Impact and vulnerability assessment

ii. Adaptation planning

iii. Implementation and feedback

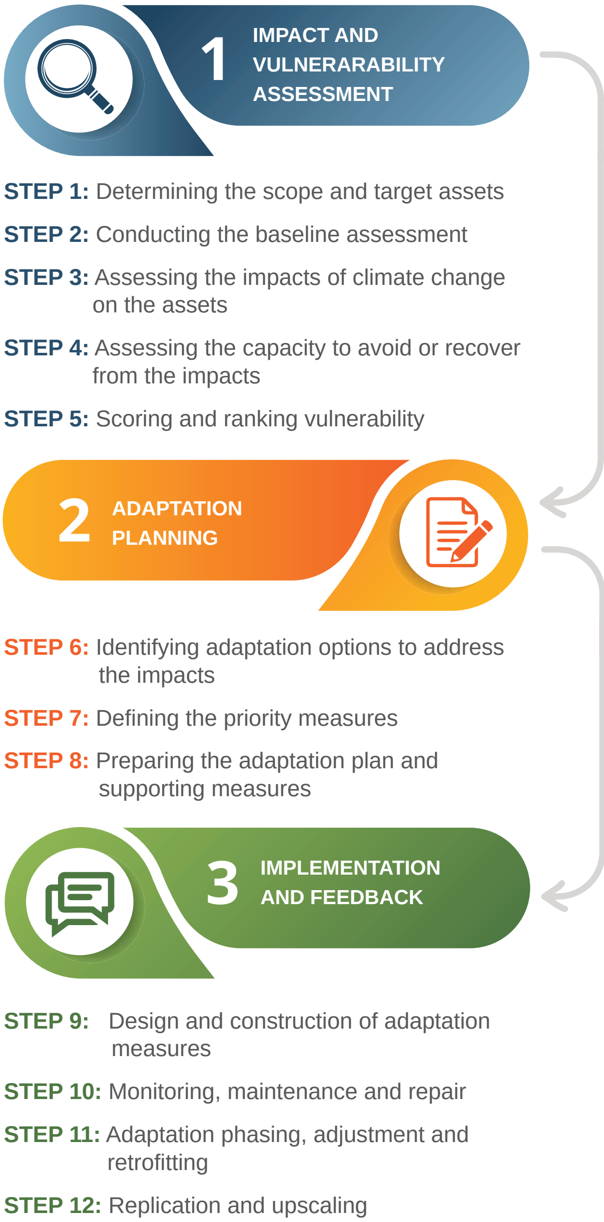


***Figure 2** Phases and steps of CAM*

Application of the vulnerability assessment and adaptation planning provides 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 on the basis of an understanding of the threats posed by climate change: exposure, sensitivity, impact and adaptive capacity. Annex 1 describes the CAM tools used for the vulnerability assessment and adaptation planning at the four Ramsar sites.

1.5 Stakeholder involvement and capacity building

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 and in validating the assessments and exploring the adaptation options throughout the process.

This process also had the benefit of field missions and stakeholder consultations conducted by the project team that were geared towards the important phases of the assessment and identification of adaptation measures, namely:

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

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

2 BASELINE ASSESSMENT FOR PONG DAM LAKE

2.1 Site description

Pong Dam lake (32˚01'N, 76˚04'E) is a reservoir situated in Kangla, Himachal Pradesh. It is located on Beas River which is one of the major rivers of Indus Basin, India. It drains a catchment area of 12,561 km^2 including 780km^2 with permanent snow. The active storage capacity of the reservoir is 7290 Mm^3 (Figure 3).

The stored water is primarily used for meeting irrigation water demands with 7913 Mm^3 released annually to irrigate 1.6 Mha. Hydropower generation is achieved by releasing the water through turbines before it is diverted to the irrigation fields. The major crops cultivated in the catchment are rice, wheat, maize and cotton. The monsoon rainfall between June and September is the main source of the water inflow into the reservoir. The snow and glacier melt runoff in the Beas catchment was studied during 1990–2004 by Kumar et al. (2007)[2], and its contribution is about 35% of the annual flow at Pandoh Dam, upstream of Pong Dam Lake.

Figure 3 *Poster of Pong Dam lake Ramsar site*
(Source: Indo-German Biodiversity Programme, Biodiversity conservation

[2]Kumar, V., Singh, P., Singh, V., 2007. Snow and glacier melt contribution in the Beas River at Pandoh Dam, Himachal Pradesh, India. Hydrol. Sci. J. 52, 376–388. https://doi.org/10.1623/hysj.52.2.376

The basin of the reservoir is concave towards the surface, and the shoreline is irregular. Pong Dam Lake has a maximum depth of 97.84 m and a mean depth of 35.7 m. Its total length is 41.8 km, with the greatest width being 19.0 km. The Pong Dam lake, also called the Maharana Pratap Sagar Reservoir, was constructed as an earthen dam across the river Beas at a place called Pong. The 396 MW hydropower dam and the reservoir are owned and managed by the Bhakhra Beas Management Board (BBMB)[3]. The reservoir creates a large man-made wetland at an altitude between 335 and 435 m msl. The area inundated varies seasonally, and the water level recedes during summers to about 384 m msl. The seasonal variation in the inundation area during 2019 is shown in Figure 4, the lighter areas showing the seasonal drawdown.

***Table 1** Seasonal change in the inundated area of Pong Dam lake*

Season	Pong Dam Lake Area (km^2)	Ramsar Wetland Area (km^2)
Non-monsoon (dead storage level)	63.1	156.62
Monsoon (full storage level)	245.0	156.62

(Source: Pong Lake Management Plan 2014)

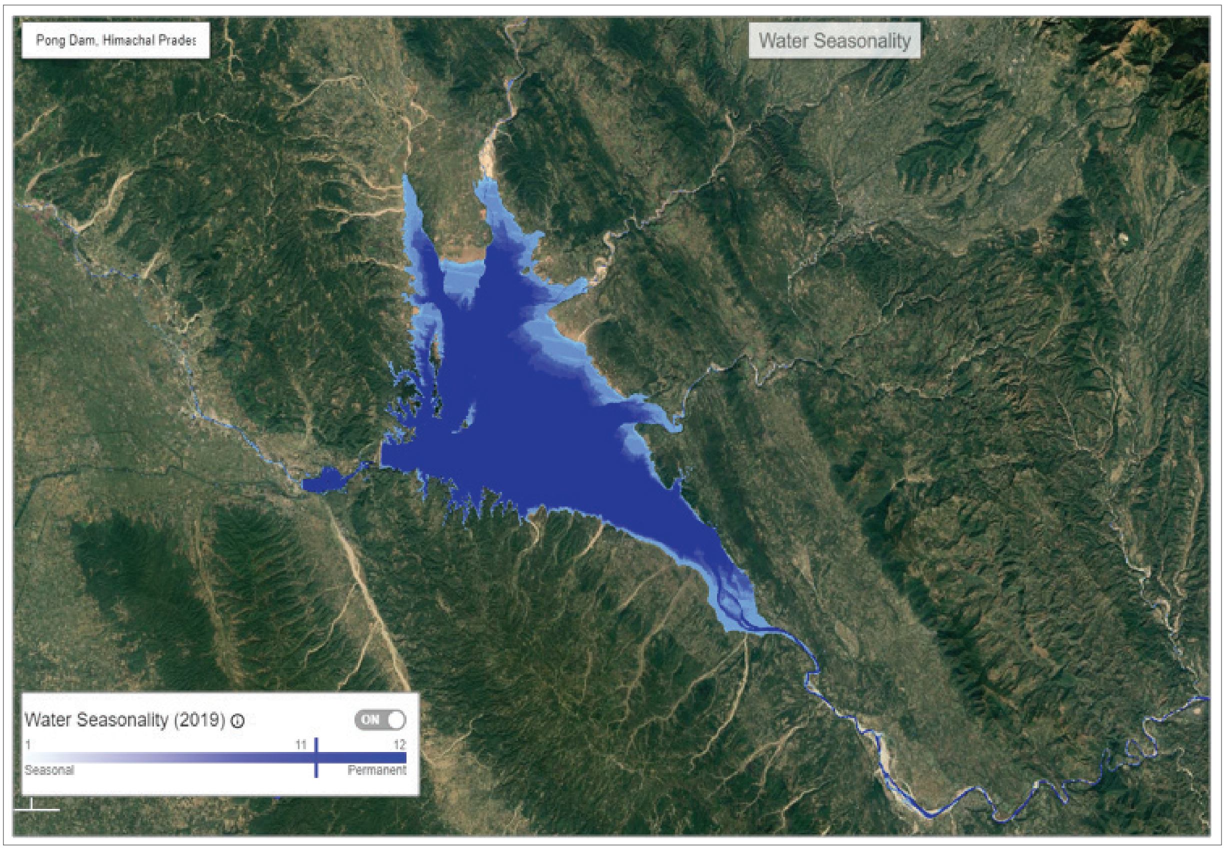


***Figure 4** Water seasonality of inundation by Pong Dam lake in 2019*
(Source: https://global-surface-water.appspot.com/map)

The lake has many seasonal and rain-fed streams, locally known as *khads,* the important ones being the Baner, Gaj and Dehar (Figure 5). With a rise in the level of the reservoir, the water extends into all these *khads,* thereby forming many bays and lagoons, of which the Dehar is the largest. These *khads* carry little to no discharge into the lake during the dry seasons (March–June and October–December) but bring in an appreciable discharge during the monsoon and winter rains. Outflows from the lake are highest in July and lowest in February, ranging from 8215 to 15,334 Mm^3.

[3]https://bbmb.gov.in/pong.htm

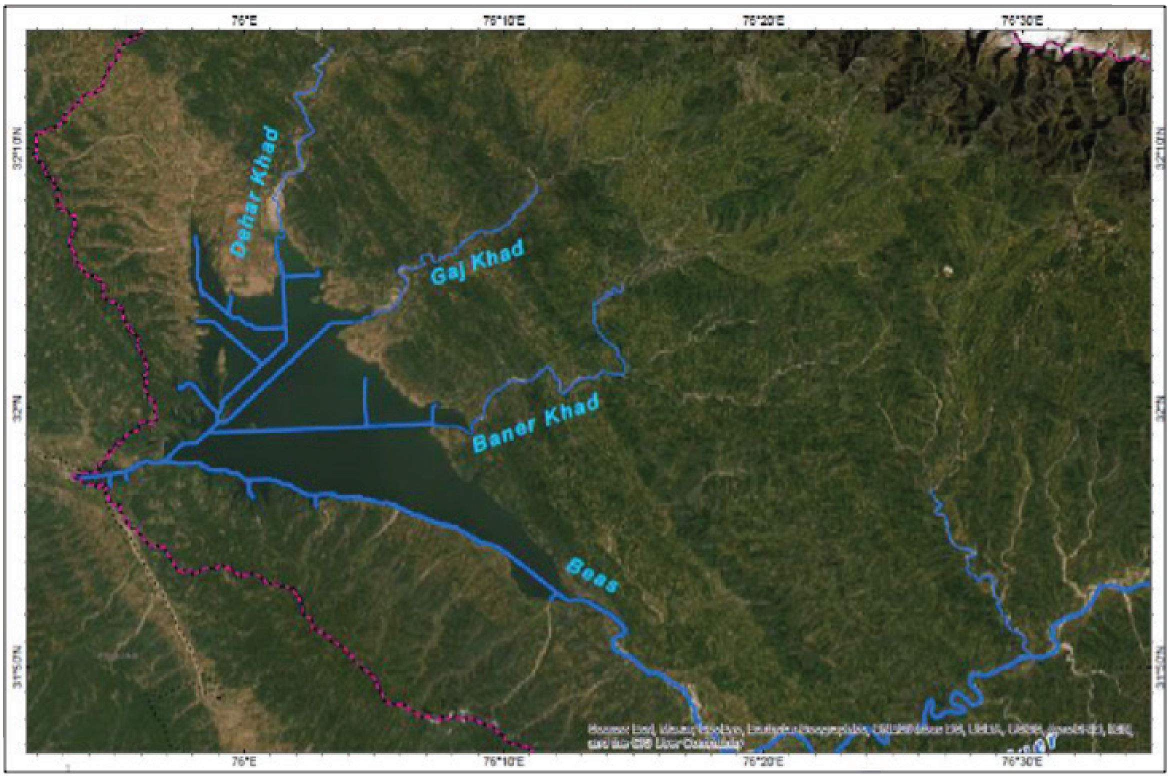


Figure 5 *Pong Dam lake and contributing tributaries*

2.2 Wetland ecology

2.2.1 Ramsar criteria and migratory birds

The Pong Dam lake was incorporated in the List of Wetlands of International Importance under the Ramsar Convention in 2002 on the basis of the immense diversity of waterfowl it supports. The wetland was designated a Ramsar site because of criteria 5 and 8.

- **Criterion 5 justification:** "More than 220 bird species belonging to 54 bird families have been identified so far (Pandey, 1989). The present waterfowl diversity of the bird sanctuary is rich. It supports 54 species of waterfowl (Pandey, 1993) compared to 39 reported before the creation of the dam (Whistler, 1926). The sanctuary is an important staging area for an annual migratory waterfowl population of more than 20,000 birds comprising mainly of Bar-headed Geese *(Anser indicus),* Northern Lapwing *(Vanellus vanellus),* Ruddy Shelduck *(Tadorna ferruginea),* Northern Pintail *(Anas acuta),* Common Teal *(Anas crecca),* Mallard *(Anas poecilorhyncha),* and Common Coot *(Fulica atra).* The Red-necked Grebe (*Podiceps griseigena)* was recorded from this reservoir for the first time in India" (Gaston and Pandey, 1987).
- **Criterion 8 justification:** "27 fish species depend on the wetland for food, spawning ground and nursery." The Pong Dam lake, located in Kangra district, of Himachal Pradesh, intercepts the Trans Himalayan Flyway. The migratory waterfowl species use the wetland as a transitory habitat during their winter migration route along the Central Asian Flyway (Figure 6). The birds remain around the lake until mid-April, which is their breeding season. It is the first major wetland offering a transitory resting reserve for migratory water birds coming from the Trans Himalayan zone (Dhadwal, 2011).

The Management Plan for Pong Dam lake 2014–2023 (D.S. Dhadwal, ACF Pong Lake) notes that about 220 bird species belonging to 54 families were recorded (Pandey, 1989; Ramsar site RIS, 2002). Between 2004 and 2011, Dhadwal photographed 426 bird species at the wetland, which is more than 70% of the bird's diversity in the whole of Himachal Pradesh. 18 species of snake, 95 species of butterfly and 24 species of mammal were also recorded in the lake area.

The most recent HPFD Annual Waterbird census figures are shown in Table 2.

Table 2 *Recent annual water bird census figures*

Year	No of birds	No of species	Migratory	Resident	Other local
2019	1,15,229	103	58	29	16
2020	1,15,701	114	60	30	24
2021	1,08,578	96	51	29	16

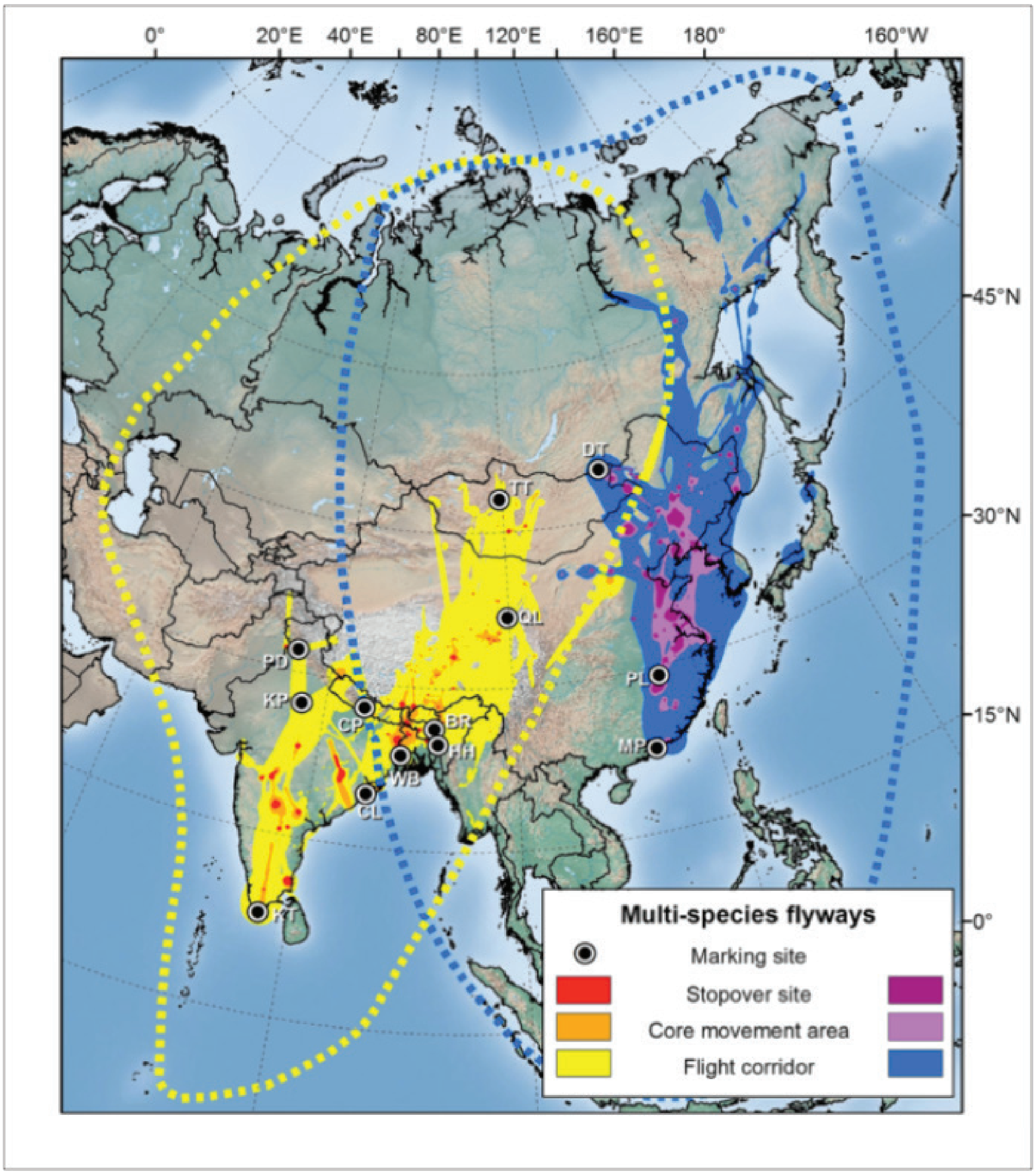


Figure 6 *Central Asian Flyway (yellow) indicating Pong Dam lake (PD) as an important stopover and marking site (Source: Palm et al., 2015)*

Very little information is available on fishes in the Beas river prior to the construction of Pong Dam Lake. A study conducted by Howel in 1916 indicates that *Oreinus sinnatus, Schizothorax richardsonii* and *Glyptosternon striatus* were present and were the three major fishes of the river Beas. After the creation of the dam, the Golden Mahseer *(Tor putitora),* Snow Trout *(Schizothorax plagiostomus)* and *Labeo dero* have started declining in their earlier habitat (Sarma et al. 2018). Similarly, *Schizothorax plagiostomus* is diminishing, while *Labeo dero* is competing to retain its presence in the lake. In 1974–75, a stocking programme started in the Pong Dam lake. Mainly seeds of Mirror Carp and major Indian carps were introduced. Rohu (*Labeo rohita),* Catla (*Catla catla),* Mrigal (*Cirrhinus mrigala)* and Wild Common Carp (*Cyprinus carpio)* are four major species that have been stocked in the reservoir, in the ratio 2:2:1:1. The fish production in the lake was highest during the years when the water level was at its maximum (Ramsar Site, RIS 2002). 25 fish species from 6 families have been recorded from Pong Dam lake (Table 3).

Table 3 *Fish species recorded in Pong Dam Lake*

Family	Species
Family Cyprinidae	*Barilius bendelisis, B. vagra, Cirrhinus mrigala, Crossocheiluls latius, Catla catla, Labeo dero, L. bata, L. crohita, Cyprinus carpio, Schizothorax richardsonii, Tor putitora, Puntius ticto, P. sarana*
Family Cobitidae	*Botia birdi, Naemacheilus kangrae*
Family Bagaridae	*Mystus aor, M. seenghala, Bagarius bagarius, Wallago atu*
Family Sisoridae	*Glyptothorax pectinopterus, G. garhwali*
Family Chanidae	*Channa marulius, C. striatus, C. cephalus*
Family Mastacembelidae	*Mastacembelus amatus*

(Source: Reports of Fisheries Department, Himachal Pradesh)

2.3 Identification of target assets

From the findings of the field missions, seven target assets were selected for further assessments (Table 4). Apart from key habitats, keystones species and wetland species, the Pong Dam lake are considered as target assets. Table 5 shows simple selection scoring for each asset. These scorings enable the team to select the most appropriate assets that represent the main characteristics of the site as reflected in its Ramsar status.

Table 4 *Selected target assets for Pong Dam lake*

Target	Asset name	Description and trends	Key issues
Physical infrastructure	Pong Dam Hydel	Main water regulating structure, dependent upon the demand for irrigation water and power	How will changes in rainfall and sediment build-up affect the operation and drawdown of the reservoir?
Key habitats	Catchment area	Rivers and streams feeding into the reservoir (12,560 km^2)	How will climate change affect river and stream flows?
	Pong Reservoir	Open deep water, Shallow water in drawdown, Dry sandbanks with little or no vegetation, Waterside vegetation and swamps below the out-fall from the dam	The reservoir water levels are managed by the dam. Extensive drawdown during the dry season and filling up in the monsoon. Sedimentation reducing the active volume. Potential for eutrophication. Water temperatures.

Target	Asset name	Description and trends	Key issues
Keystone species	Bar-headed Goose (BHG) and Northern Pintail (NP)	Bar-headed Geese (>45% of the world's population) and Northern Pintails are seen in the large congregations in this wetland. In 2020, the total count of these birds at the lake was 29,443, while in 2021, 49,496 Bar-headed Geese visited the lake. Bar headed Geese breed in high-altitude wetlands that are at altitudes of 4000–5000 m.	Why is Pong Dam an attractive migration staging point? Right distance, right winter climate, shelter from disturbance, food supply? How will climate change affect these attractions?
	Golden Mahseer *(Tor putitora)*	The Golden Mahseer, *Tor putitora* Hamilton, one of the largest freshwater fishes of the Indian sub-continent, inhabits mainly Himalayan rivers in the foothills.	Migratory cold-water fish species, moving up the inflowing streams to breed
Wetland species important for Ramsar	Migratory birds	The most important habitat is found at Nagrota Surian. More generally it is the northern shoreline and flat shallow areas that retain aquatic plants and rhizomes, mudflats with access to arable land for lapwings and geese. The count of migratory birds has been almost constant in the last 10 years (2010–2020), with no specific trend.	Suggest that this is covered by considering the main habitats where migratory birds stay? Specific migratory birds considered under keystone species
Ecosystem services	Fisheries	Pong Reservoir has a huge potential of fisheries resources, with an average water spread area of 15,000 ha. No specific data are available on the fish count, but those obtained from the Fishing Department suggest that the amount caught significantly depends upon the reservoir level.	Fisheries stocking? How much of the fish production is dependent upon stocking with fish by the Fisheries Department?

Table 5 *Scoring for asset selection*

Criterion	Question	Pong Dam hydel	Catchment area	Pong Reservoir	BHG and NP	Golden Mahaseer	Migratory birds	Fisheries
Representativeness	To what extent is the habitat, species or ecosystem service representative of the site?	4	5	5	4	4	5	3
Ecological significance	To what extent is the habitat, species or ecosystem service significant for ecological processes?	3	5	5	5	5	5	4
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?	3	3	5	4	4	5	4

Criterion	Question	Pong Dam hydel	Catchment area	Pong Reservoir	BHG and NP	Golden Mahaseer	Migratory birds	Fisheries
Representativeness	To what extent has the habitat area/condition, species numbers or productivity of ecosystem service varied over the past 20 years as conditions change?	4	5	5	4	4	5	3
Non-Climate Threats	To what extent is the asset threatened by non-climate challenges, or is the focus for management?	3	5	5	5	5	5	4
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	3	5	4	4	5	4
Sum the scores for each asset		**20**	**25**	**29**	**23**	**23**	**26**	**21**

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

2.4 Catchment and hydrology

2.4.1 Catchment

Figure 7 shows the profile of the Beas river basin, including the elevation, soils, land use, weather grid and stream gauge locations.

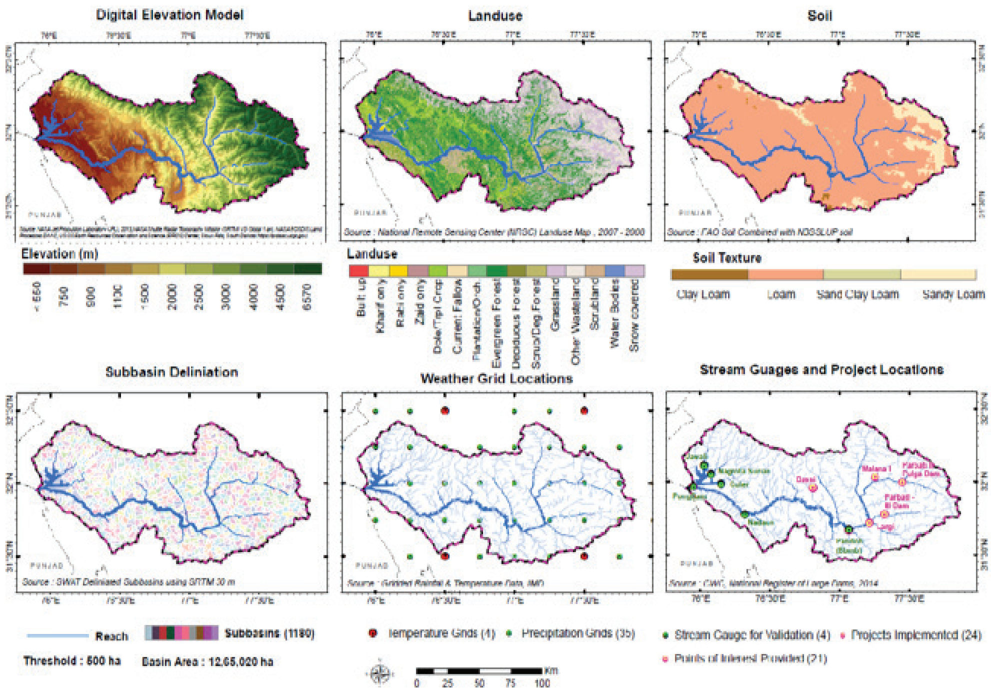


Figure 7 *Beas rivers basin delineated with respect to Pong Dam lake. The figure includes the elevation, land use, soil, sub-basin, weather grids (IMD gridded) and stream gauge information. (Source: INRM Generated Maps)*

In the last decade, the land-use/land-cover (LULC) transformation has been significant in the Pong Dam lake catchment because of human activities. Major changes can be observed in the extent of agricultural land at the cost of other land-uses. These changes have affected the water quality and habitats of the wetland. LULC changes have led to variations in the hydrological cycle. From 2010 to 2020, the agriculture area increased by 17% and the built-up area increased by 65% (Table 6). In that decade, the forest land in the Pong catchment decreased by 8% and barren land decreased by 16%. Table 6 and Figure 8 show the conversion of forest land and barren land for agriculture. The conversions to agricultural land tend to increase the rate of sedimentation in the wetland, which in turn can affect hydropower production and reservoir storage capacity. Apart from sedimentation, the increase in agriculture affects the water quality. Sedimentation is likely to continue increasing due to large-scale urbanisation and development, especially at major tourist places. Tourist places such as Kullu, Manali, Dharmshala and Palampur, which lie within the Beas river catchment, have experienced major increases in the built-up area.

***Table 6** Percentage change in LULC in the decade 2010–2020*

Land use class	Area 2010 (%)	Area 2020 (%)	Percentage change (2010–2020)
Agriculture	11.6	13.5	16.7
Barren land	6.4	5.3	-16.4
Built-up area	1.8	3.0	65.6
Forest	53.0	48.7	-8.3
Snow	24.6	26.0	5.3
River channel	1.9	2.0	8.1
Waterbody	0.8	1.7	103.6

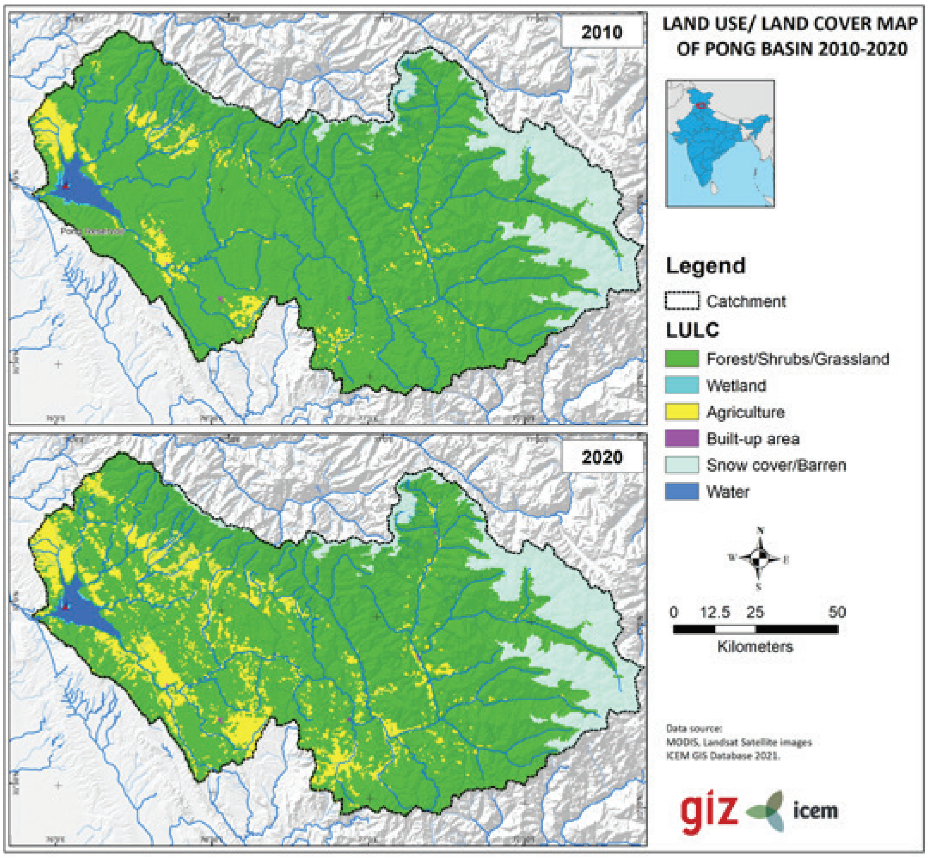


***Figure 8** LULC maps of the Pong Dam lake basin for assessing the decadal change during 2010–2020*

An inventory of the glaciers and glacial lakes in Himachal Pradesh carried out in 2004 (Bhagat et al., 2004)[4] identified 358 glaciers with a total area of 768 km^2 and 74 glacial lakes with a total area of 236 km^2 within the Beas river basin (Figure 9a). It is apparent that these glaciers and lakes feed into the mainstream of the Beas river. None of the other tributaries flowing into Pong Dam lake has glaciers. All the snow and glacier melt water will pass through Pandoh Dam, located about 150 km above Pong Dam lake. Pandoh Dam is a run-of-river hydropower plant (990 MW) diverting 256 m^3/s of water from the Beas river into the Sutlej river.

Of 22 major glacial lakes, 5 are potentially dangerous for glacial lake outburst floods (GLOFs), being located close to the glacier, hanging with moraine dams. The lakes with GLOF potential are shown in Figure 9b. In 2004, Bhagat et al. reported that all the potentially dangerous lakes are situated within fast-retreating glaciers and that the lakes are rapidly increasing.

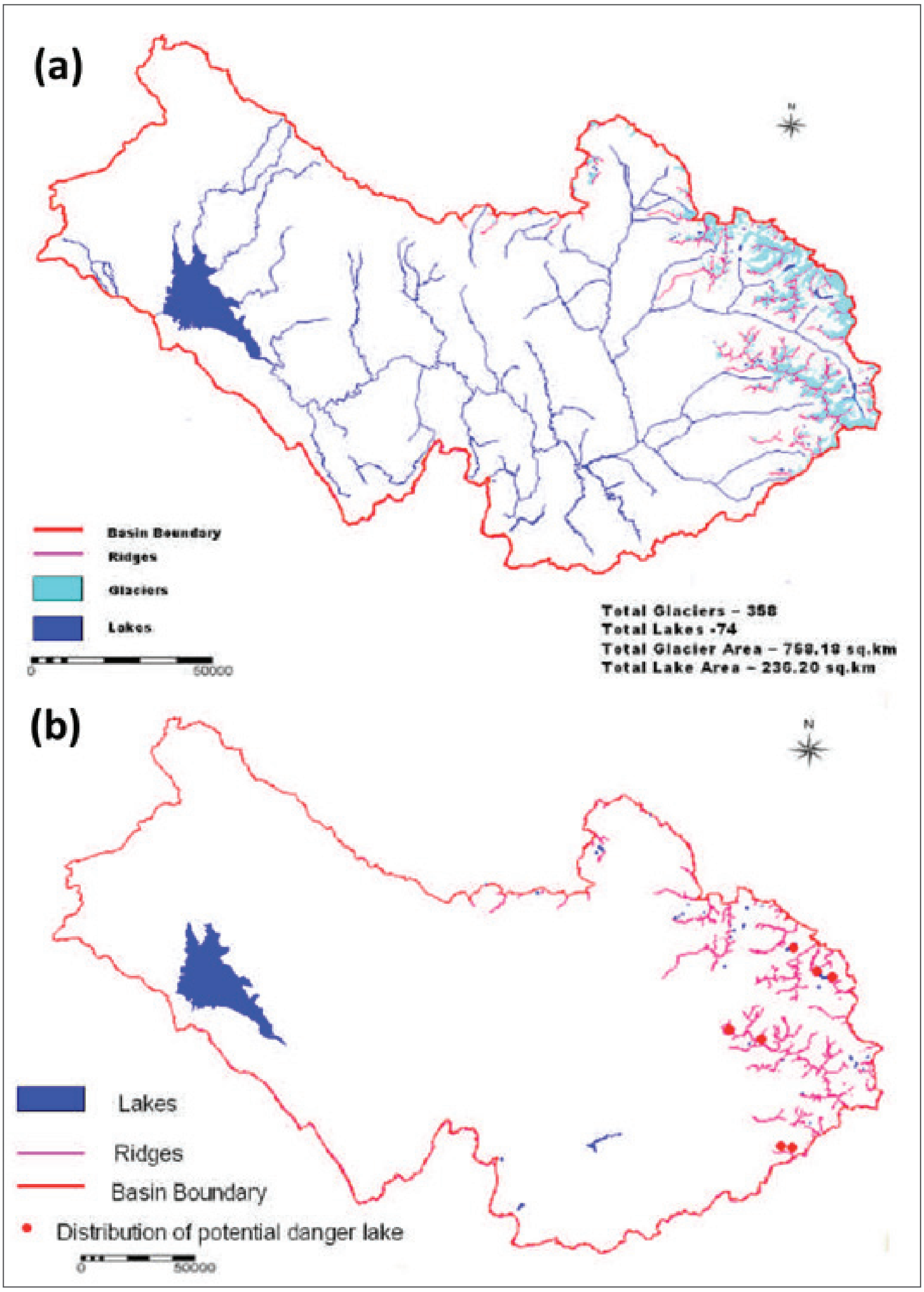


Figure 9 *(a) Glaciers and glacial lakes in the Beas river basin; (b) potentially dangerous GLOF lakes (Source: Bhagat et al., 2004.)*[4]

[4]Rajiv M Bhagat, Vaibhav Kalia, Chitra Sood, Pradeep Kumar Mool & Samjwal Ratna Bajracharya (2004) Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of Himalayan Region. ICIMOD & UNEP

2.4.2 Pong Dam Hydel

Pong Dam was completed in 1974. It is a 133 m tall, 1951 m long earth-fill embankment dam with its crest sitting at an elevation of 435 m above sea level. It is a multi-purpose dam providing water for irrigation, drinking water and power. The powerhouse, with 6 x 66 MW Francis turbines (396 MW), is located at the base of the dam, with a maximum head of 95 m. After power generation, the water passes into a downstream regulating pond distributing the water into a left bank irrigation water channel, with surplus water being released into the Beas river, with riparian marshy areas. The dam's spillway is a chute-type spillway controlled by six radial gates with a maximum discharge capacity of 12,375 m^3/s.

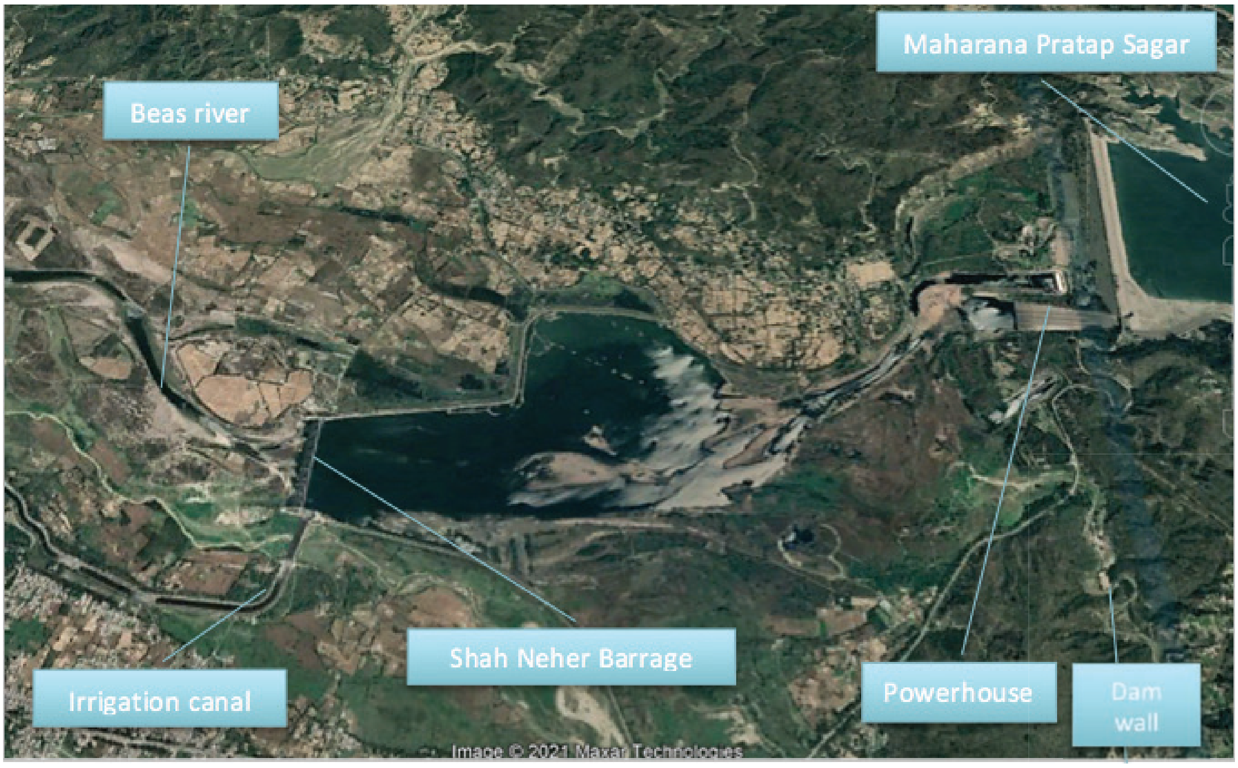


***Figure 10** Google Earth image of Pong Dam and associated hydraulic structures (Source: Google Earth image 2021)*

The reservoir operation is integrated to optimise the benefits of irrigation and power. Water is stored in the reservoir during the summer and rainy season and released in a regulated manner during lean periods in a fixed schedule of filling period–depletion period for the reservoir. The filling period is from 21 June to 20 September, and the depletion period is from 21 September to 20 June.

Pong Dam (with the cascade dams of Bakhra and Pandoh) provides water for irrigation and drinking to the states of Punjab, Haryana and Rajasthan, and the cities of Delhi and Chandigarh. It is managed by the BBMB, which authorises the monthly releases required by the partner states.

2.5 Key habitats

2.5.1 Pong Reservoir

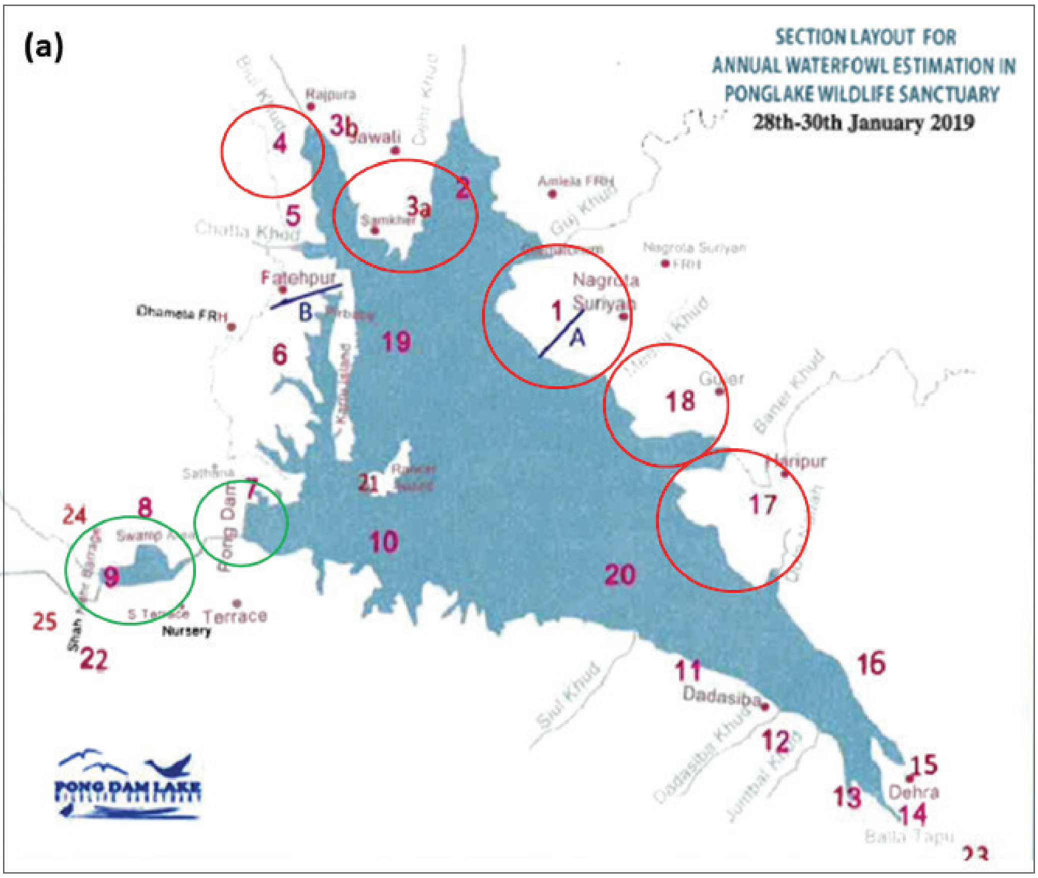
Pong Dam lake, a reservoir created by the dam, has a gross capacity of 8570 Mm^3 with a 7290 Mm^3 active capacity. The reservoir has a normal elevation of 426.72 masl, at which the area is 260 km^2. When full at 435 masl, the reservoir extends 41.8 km upstream from the dam and covers a surface of 450 km^2. It has a maximum depth of 97.84 m and a mean depth of 35.7 m. The seasonal drawdown of the reservoir thus exposes a total of 190 km^2 of sand and mudflats around the periphery of the reservoir.

The study carried out by INRM (2020) on the climate and hydrological risks associated with the ecosystem functioning of Pong Dam lake noted that there has been a slight increase in the sedimentation rate from 24.62 Mm^3/year in 2008–2009 to 25.79 Mm^3/year in 2015–2016. About 25% of this increase falls out in the dead storage zone, while the larger proportion settles in the active storage zone. This increase is within the moderate/medium range according to the Handbook for Assessing and Managing Reservoir Sedimentation, published by CWC. The sedimentation rate is expected to increase incrementally through to the end of the century due to large-scale unregulated and unplanned development in the area as well as an increase in extreme events and increase in flow, rising to 33 Mm^3/year INRM (2020). That load may require dredging or desilting of the reservoir area. Turbidity analysis of the reservoir waters shows that most of the sediment comes down the Beas river and, to a lesser extent, down the Dehar, Gaj and Baner *khads.*

The water quality in the reservoir is being monitored since the 1990s, and whilst the data cannot be statistically analysed, there is an apparent trend towards increasing surface water temperature and decreasing dissolved oxygen (DO). The 2020 figures show a surface temperature of 26ºC compared with 23ºC in the 1990s and a decrease in dissolved oxygen from between 8-9mg/l in the early 1990s to under 7 mg/l. Other parameters such as BOD, COD and total dissolved solids and conductivity are within the water quality standards, and the nutrients nitrate and phosphate are below threshold levels of concern for eutrophication (INRM, 2021)[5].

2.5.2 Migratory bird habitat

The migratory birds use the areas around Pong Dam lake as a staging post on their migrations from the summer habitats north of the Himalayas and on their return at the end of winter. Some birds will remain there during winter. The main areas where they collect are the shallows and shoreline of the lake, especially on the northeastern shore, around Nagrota Surian, and the deltas that have formed around the incoming *khads* (streams) (Figure 11). These areas provide the roosting and resting spaces that are safe from predators and hunting and provide access to food – aquatic plants, invertebrates and terrestrial sources, e.g., grasses, grains and crops.



[5]INRM (2020) Modeling Climate and Hydrological Risks Associated with Ecosystem Functioning of Pong Reservoir, Himachal Pradesh. Report for GIZ India.

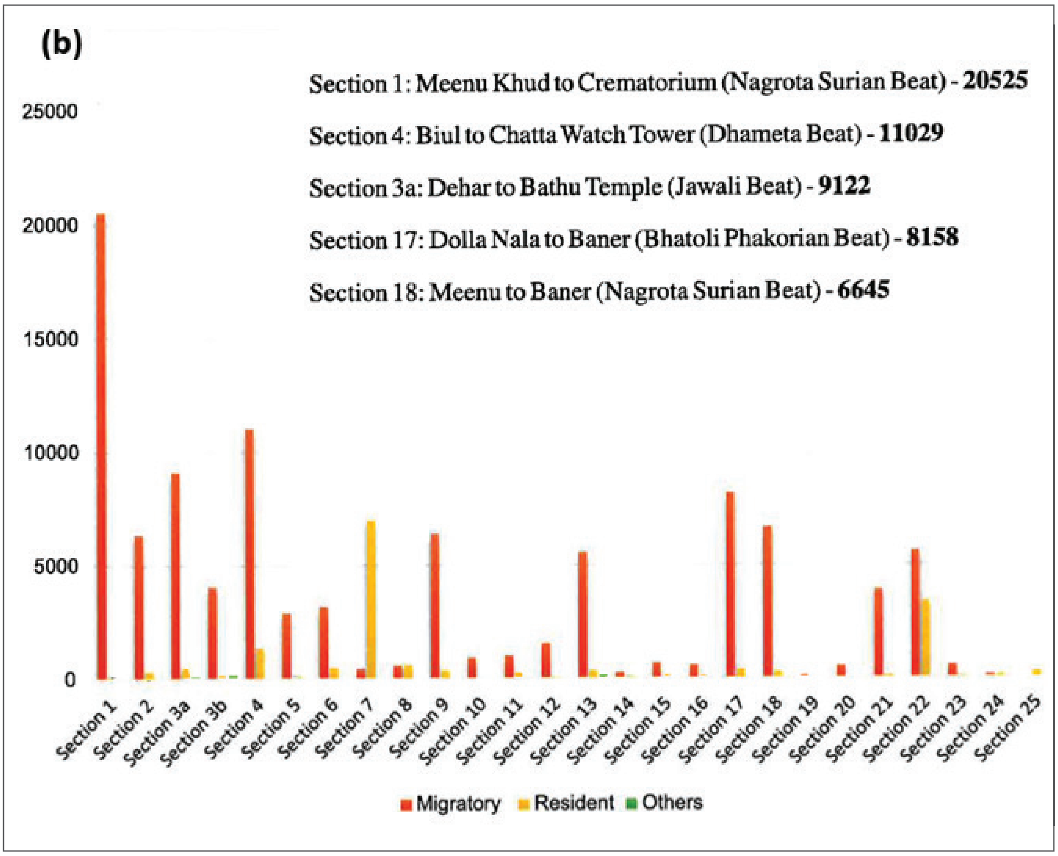


Figure 11 *Preferred locations for (a) migratory and (b) resident water birds around Pong Dam (Source: Pong Dam Annual Waterfowl Estimate 2019)*

2.6 Keystone and Ramsar-important species

2.6.1 Bar-headed Goose and Northern Pintail

The Bar-headed Goose *(Anser indicus)* is one of the most significant migratory birds visiting Pong Dam lake, migrating over the Himalaya to spend the winter in parts of South Asia, from Assam to as far south as Tamil Nadu. It is one of the world's highest-flying birds, adapted to breathe at very high altitudes, peaking at around 6400 m. It arrives at the lake in autumn at the end of the monsoon and departs in March. The modern winter habitat of the species around Pong Dam Lake is cultivated fields and grasses in the drawdown area, where it feeds on barley, rice and wheat and may damage crops.
The summer habitat is high-altitude lakes, where the bird grazes on short grass. The only breeding site in India is Tso Moriri, in Ladakh. It suffers predation from crows, foxes, ravens, sea eagles, gulls and others. Avian flu outbreaks can also impact the population. However, the total population might be increasing even though it is complex to assess population trends as this species occurs over an area of more than 2,500,000 km^2.

The Northern Pintail *(Anas acuta)* is a bird of open wetlands that nests on the ground, often some distance from water. It is migratory and winters south of its breeding range to the equator. It has a wide geographic range breeding in northern areas of Europe and across the Palearctic and North America. It feeds by dabbling for plant food and adds small invertebrates to its diet during the nesting season. The winter diet is mainly plant material, including seeds and rhizomes of aquatic plants, but the Pintail sometimes feeds on roots, grains and other seeds in fields though less frequently than other *Anas* ducks. The Pintail feeds mainly in the evening or at night, and therefore spends much of the day resting. Its long neck enables it to take food items from the bottom of water bodies up to 30 cm deep, which is beyond the reach of other dabbling ducks such as the mallard. It is highly gregarious outside the breeding season and forms very large mixed flocks with other ducks.

The Northern Pintail's breeding habitat is open unwooded wetlands, such as wet grassland, lakesides or tundra. In winter, it will use a wider range of open habitats, such as sheltered estuaries, brackish marshes and coastal lagoons. During the nesting season, the Pintail mainly feeds on invertebrates, including aquatic insects, molluscs and crustaceans.
The population is affected by predators, parasites and avian diseases. Human activities, such as agriculture, hunting and fishing, have also had a significant impact on the numbers. Nevertheless, owing to the huge range and large population of this species, it is not threatened globally.

2.6.2 Golden Mahseer

The Golden Mahseer *(Tor putitora)* is an endangered species of cyprinid fish found in rapid streams, riverine pools and lakes in the Himalayan region. Its native range is within the basins of the Indus, Ganges and Brahmaputra rivers. According to FishBase[6] it is a benthopelagic freshwater species preferring waters with a pH range from 7.4 to 8.0 and temperature from 13°C to 30°C. It occurs in the sub-tropics between 34°N and 20°N. It is a popular gamefish. Once it was believed to be the largest species of mahseer, which could reach up to 2.75 m in length and 54 kg in weight though most caught today are far smaller. Now, specimens over 30 cm in length and 5 kg in weight are rarely caught.

The Golden Mahseer is omnivorous, feeding on fish, zooplankton, dipteran larvae and plant matter. Juveniles subsist on plankton while fingerlings feed mainly on algae. The fishr migrates upstreams and rivers to breed over gravel and stones and returns to perennial ponds after breeding. Spawning takes place during the low phase of floods. Fry are found among the stony margins of the streams. The species is threatened by habitat loss, habitat degradation and overfishing, and in the past decade, its population has declined by more than 50%.

2.7 Ecosystems services

There are over 60 small and large villages, with a total population of more than 30,000 people, managing 12,000 cattle in the immediate area surrounding Pong Dam lake (Figure 12). About 2000 families are directly dependent on the lake for commercial fishing, which has been practised from the beginning of lake inundation. Another 3500 families are dependent on agriculture crops in the drawdown area. In addition to local people, the migratory graziers like the Gaddies and Gujjars benefit from the lake. About 20,000 cattle, domestic and nomadic, graze there. The villages include people who were displaced by the construction of the dam and reservoir – the so-called "oustees". This group of villagers is dependent on the Ramsar site and its services for their livelihoods. They cultivate crops in drawdown areas, fish in the reservoir, extract NTFPs and harvest wildlife.

There are some 3038 licenced fishermen catching fish in the lake as their principal livelihood. The average annual catch is about 400 tonnes of fish, and there are 15 fish-landing sites around the periphery of the lake (Figure 12). Community-based ecotourism on the Pong Dam lake is being encouraged as part of the management plan, which notes the following attractions:

- Bird watching
- Boating
- Fishing and angling
- Trekking trails on the fringes and in nearby hill areas
- Religious and cultural tourism
- Water sports such as swimming, yachting and canoeing

There are 13 proposed eco-tourism areas identified for different activities (Figure 12).

[6]https://www.fishbase.se/summary/Tor-putitora

Figure 12 Towns and villages surrounding Pong Dam lake

2.8 Stakeholder roles and perceptions

Around Pong Dam lake, there are different stakeholders or groups involved in the use or management of the Ramsar site and its natural resources, including official organisations, the private sector, user groups and communities (Table 7). Stakeholders' perceptions of existing climate regimes and recent extreme events in Pong Dam Lake are summarised in Table 8.

Table 7 Stakeholder analysis for Pong Dam lake

Stakeholder	Description
Forest Department	Management of nearby forest, eco-tourism, wildlife, monitoring and evaluation of flora and fauna
Wetland authority	Nodal agency for coordination of the Wetland Conservation Programme, which aims to conserve and restore wetlands with the active participation of the local community at the planning, implementation and monitoring levels. Aims to conserve and restore the habitats for migratory and resident species of birds of the area, to conserve the indigenous fish species and make fishery a sustainable livelihood for the local fishermen, to harmonise the relation between fishermen, wildlife and farmers, to enhance the income of the local people by undertaking the income generation in potential area, propagation of eco-tourism in the area to generate employment, to make the tourists more sensitive towards the values of nature and wetlands.
The Bhakra Beas Management Board (BBMB)	BBMB is the primary owner of Pong Dam and its reservoir. It regulates the hydrology of the reservoir as well as the catchment. Since its historical presence, it carries out developmental and eco-developmental activities through village-level societies and thus is a key player in the management of the area.

Stakeholder	Description
Fisheries Department	Empowered by the Himachal Fisheries Act, which introduces commercial fish species – mixes carp into the reservoir every year – native fishery has been declining. Their mandate includes development of the reservoir fishery and protecting and conserving the reservoir and lacustrine fisheries resources of the state and regulating and enforcing rules related to fishing and development of fisheries.
Tourism Department	HP Tourism Department aims to make sustainable tourism an engine of socio-economic growth. It supports eco-tourism development around Pong Dam. The wide variety of birds attracts bird lovers and environmentalists. The eco-tourism helps in the improvement of the socio-economic condition of the local people, providing alternate sources of income generation. The eco-tourism is proposed to be managed through the local registered societies with adequate representation of the local stakeholders. The angling competition also attracts tourists.
Pong Lake Biodiversity Conservation Society (PLBCS)	This society comprises representatives of different concerned departments (fisheries, revenue, police, tourism, forest and BBMB). The Chief Conservator Wildlife (Forest), Dharamsala, is the chairman of the society, which has been duly registered under the Societies Act. It aims to launch lake conservation activities and promote eco-tourism in the Pong Lake area and charges entry fees for tourist vehicles.
Fishermen	3038 fishermen who depend on the lake for their livelihood. There are organised fishermen cooperative societies regulated by the state fisheries department.
Farmers	Large tracts along the shoreline are farmed for food grains during the drawdown phase of the reservoir. The land is a notified sanctuary and is owned by the BBMB. Even though farming these areas is illegal, farmers consider it their traditional right to farm them. This group is politically organised and includes some oustees displaced by the dam and reservoir.
Residents of the watershed	This group includes residents of the catchments that are associated but not in an obvious manner like fishers and farmers. Activities in the larger catchment of Beas have an impact on Pong Lake Reservoir.
Water sports complex	The water sports complex regularly organises training programmes in water sports. These activities cause significant disturbance to the lake and are largely uncontrolled[7].
Hydropower companies in the watershed	Micro- and mini-hydel projects directly affect the hydrology and therefore the ecology of small streams that in turn affect the larger streams/*khads.* The *khads* draining into the Pong Reservoir are directly affected by these developments.
Pong oustees committee	This group of villagers from surrounding areas is extensively dependent on the sanctuary land for their livelihood. They cultivate crops in drawdown areas, fish in the reservoir and extract NTFP. The settlement of their land and compensation since the construction of the dam is still pending. They are organised and are politically influential, They act as a pressure group against commercial interests and other farmers with large land holdings in the encroached areas.

[7]Quoted from Pong Dam Management Plan 2014 – 2023

Table 8 Stakeholders' perceptions in Pong Dam lake

Stakeholder	Perceptions on existing climate regime and recent extreme events, and concerns about climate change
Forest Department	There has been no visible impact of climate change on the wetland at this stage. Mostly human interference is the major factor with respect to the conservation of wetlands and degrading trends in the catchment.
Wetland Authority	The impacts of climate change are mostly indeterminate, but siltation is increasing, and eutrophication is a potential problem, with increasing temperatures and reduced rainfall during the dry season.
BBMB	Some specific changes observed may be due to climate change, such as the increase in evaporation. There is a change in the rainfall pattern (March to April), with more rain now from April to August – less rain than in the past. But not much change in annual precipitation.
Fisheries	There is a change in the breeding season of the fishes, requiring adjustment of the fishing seasons – as fishing is not permitted during the breeding season.
Fishermen	Some specific types of fisheries are reducing, the cause is unknown, but climate change may be a factor.

Some of the major drivers and factors responsible for the degradation of the Pong Dam lake and its catchment are shown in Table 9.

Table 9 *Pong Dam lake degradation factors*

Degradation factor	Relevance for Pong Dam wetland
Releasing of agricultural chemicals from agriculture	Sources from croplands surrounding the reservoir
Tilling for crop productions	Agriculture within the drawdown area
Population pressure	Increasing populations in communities surrounding the reservoir, currently about 30,000 people
Grazing	12,000 cattle grazed around the reservoir, plus many more cattle grazed by nomads
Human sewage	Potential from communities and tourism facilities
Nutrient influx	Nutrients washed into the reservoir on sediments, and from agricultural run-off
Weeds and eutrophication	Increase in nutrients causing growth in aquatic vegetation and algae
Solid waste pollutants like plastics	Potential from local communities and visitors
Introduction of non-native species	The Management Plan mentions that non-native terrestrial weeds such as *Lantana,* Congress grass, *Cassia tora* and *Lucaena* need eradication.
Increased siltation	Strong risk of increased sedimentation from catchment

2.9 Current management arrangements and plans

2.9.1 Organisations responsible for site management

The operation of the hydropower and irrigation dam is managed by the BBMB, which has established an Environment and Climate Change Cell for the management of environmental issues and addressing the impacts of climate change on all its dams and reservoirs, including Pong Dam lake.

The forested areas around the Pong Dam lake between 430 and 442 masl, or about 750 m from the maximum reservoir level of 433.12 masl, are an eco-sensitive zone and are managed by the Divisional Forest Officer. The control of the forests in the buffer zone, i.e., multiple-use zones, is the responsibility of the DFO. Nurpur and Dehra. The staffing includes one ACF, two Forest Rangers, five Deputy Rangers and 16 Forest Guards. However, the casual staff are engaged on daily wages for the protection of the migratory birds in the lake during the winter months only. The setting up of a research, monitoring and training centre is proposed as a permanent bird ringing and monitoring station.

2.9.2 Current management measures

In 1983, the entire lake was declared a wildlife sanctuary by the Himachal Pradesh Government (Bird Sanctuary Notification, 207 km^2). A management plan (Chandra, 1992) for the Pong Dam Bird Sanctuary addresses issues inside the PA boundaries such as protection, habitat improvement, tourism and its regulation, roads, and staff quarters. The Forest Department undertakes plantation work in the peripheral area of the lake to check the silt build-up as well as provides nesting and roosting places for the birds. The island of Ramsar was developed for nature conservation education with a rest house built there and a boating facility provided for visiting school children.

In the 2014 Management Plan, three zones are proposed for the management of the sanctuary, each with different activities that are allowed and defining conservation and rehabilitation measures (Figure 13) (Dhadwal, 2014). The plan sets out the following zones:

1. **Core Zone or Conservation Zone:** Activities mainly for wetland birds.

- Construction of shallow water ponds with reeds to arrest the receding water.
- Species-specific habitat creation and extension for rare species such as the Sarus Crane, Black-Bellied Tern, Indian Skimmer and River Tern
- Fish farming for different fish species of the reservoir
- Constructing diversion channels to provide swampy conditions and water to the fish farms, mounds and ponds
- Collecting and disposing non-bio-degradable garbage and waste after the monsoon

2. **Rehabilitation Zone:** Haven for resident and altitudinal migrants.

- Afforestation of forestry plant species of different canopies with bushes, herbs, grasses and wild fruit plants
- Creating conditions for rodents and reptiles to flourish and in turn attracting raptors to these areas
- Soil and water conservation works
- Channelisation and diversion of *khads* to create additional areas for plantation and other habitat improvement activities

3. **Multiple-use Zone:**

- Creation of alternate livelihoods for local people to reduce direct dependence on lake resources.
- Eco-development activities and promotion of village tourism
- Construction of the ring road, mainly at 1410 msl.
- Promoting organic farming and reducing chemical usage in the buffer area

The rate of sedimentation needs regulation in the Pong Dam lake through afforestation and adoption of agroforestry practices in the agricultural sector. Frequent flooding as has occurred in past years poses a serious threat to the wetland ecology, the biodiversity and the human settlements downstream of the dam. It calls for corrective actions and preventive measures from the concerned authorities and stakeholders. Those needed measures include:

- An early flood warning system at the basin scale (with increased risk of extreme rainfall events)
- Periodic desilting of water bodies and reservoirs
- Installation of silt traps at the entry points of the wetland and a vegetated buffer around the reservoir
- An effective waste management system
- Extensive afforestation and maintenance

Wetland management usually involves multiple stakeholders. There is no blueprint for balancing conservation and development in all wetlands. Establishing the trade-offs between use and conservation depends on identifying the characteristics of the wetland, the ways in which it is used and the values that people place on it. It also requires consideration of the national and international biodiversity importance.

There are several challenges to establishing these parameters for trade-offs. A participatory and integrated water resource management approach is needed. If the local people are fully included in planning and management discussions, the results can be very successful. Involving local communities and wetland users in the process of establishing trade-offs is essential. For e.g. local people in collaboration with research institutes and government agencies need to determine which parts of the wetland can be used for fishing and how rotational and seasonal regimes should be managed to allow stocks to recover. Local fishermen should receive training in fisheries management to reduce the risk of overfishing and the use of damaging methods. Development of eco-tourism should be encouraged so that alternative sources of income are generated for some communities, making them less dependent on the reserve's resources.

The local communities in the Pong Dam area are fundamentally linked to the wetlands, from their core requirements of water and food to the choices and trade-offs they make and the governance systems that influence their behaviour in and around the site. Involving local people encourages them to actively participate in conservation management. It leads to mutually agreed solutions, representing a balance between various wetland uses that is locally and politically acceptable and respecting state and national environmental laws. Compromise practices may not always be the 'best' options in terms of conservation or development – the consultative process needs to resolve competing demands and arrive at the appropriate balance. Underlying this balancing process is the fundamental imperative of achieving net biodiversity gain and preventing a steady degradation of biodiversity values.

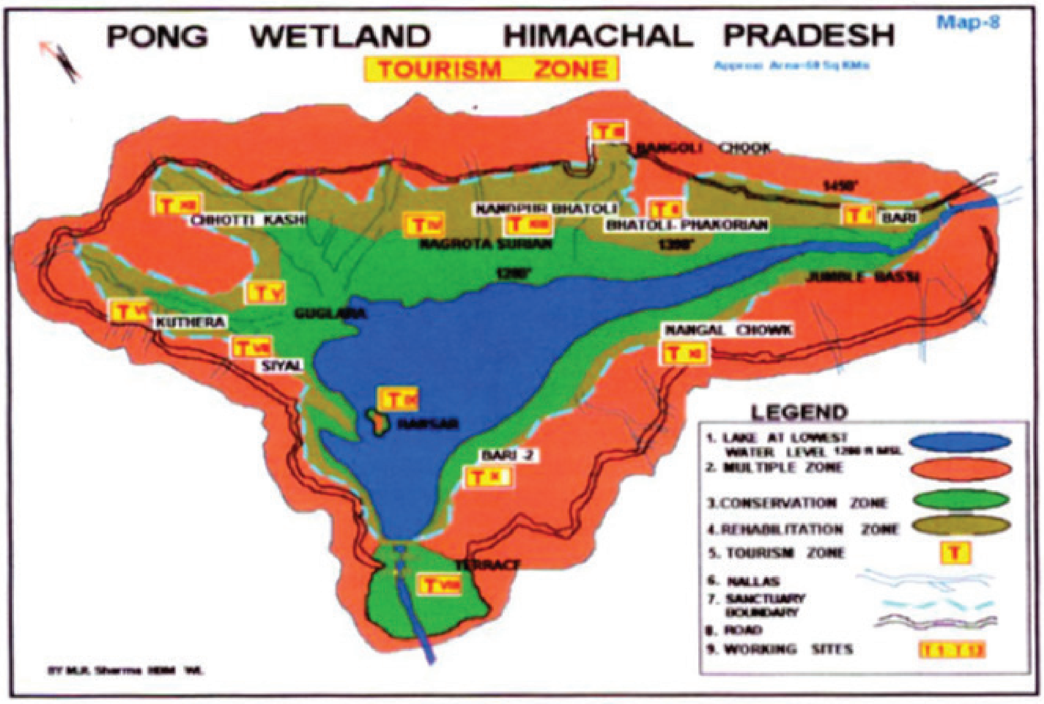


__Figure 13__ Zonation of the area around Pong Dam sanctuary, with identified eco-tourism zones (Source: 2014 Management Plan)

3 CLIMATE CHANGE AT PONG DAM LAKE

3.1 Current and past climate

The Pong Dam lake is in the Outer Himalaya geo-climate zone, which is one of the three geo-climate zones in Himachal Pradesh (along with the Inner Himalaya and Alpine zones). In the Outer Himalaya geo-climate zone, a year is divided into four seasons. Winter extends from January to February; summer (or pre-monsoon) runs from March to May; summer is followed by the SW monsoon period, extending from June to September; and the NE monsoon (or post-monsoon) is from October to December.

3.1.1 Precipitation

The Pong Dam lake is among areas receiving the highest rainfall in the state (Figure 14) (IMD, 2020)[8]. The total average rainfall during the SW monsoon is 1479.8 mm, which accounts for 82% of the annual rainfall in this area (1806.4 mm). The average rainfall rapidly increases during June–July, from 177.7 mm to 508.2 mm, and reaches 589.0 mm during August, before reducing to 204.8 mm in September. A trend analysis based on the past 30 years' (1989–2018) observations shows a slight decrease in rainfall in Kangra district during the SW monsoon season, resulting in a decrease in the annual rainfall.

The average frequency of rainy days during June–September in the Pong Dam lake area ranges from 30.3 to 37.5 days (Figure 15). At the annual scale, the average frequency is about 40–53.1 days. Importantly, the frequency of rainy days has significantly reduced over time (IMD, 2020).

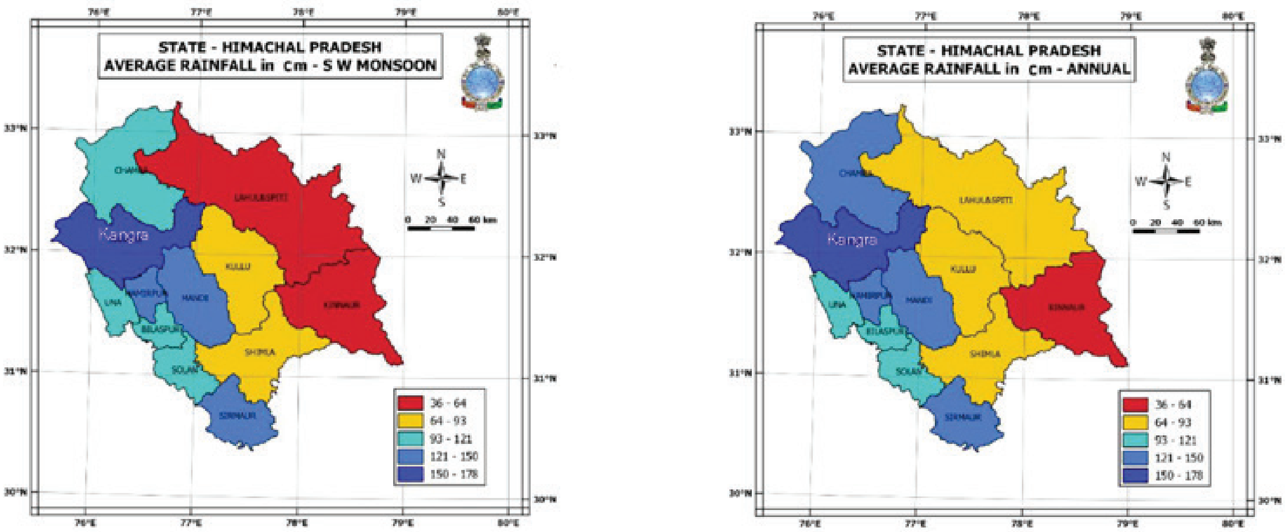


Figure 14 *Mean rainfall patterns of Himachal Pradesh. Pong Dam lake is located in Kangra district. (Source: IMD 2020)*

[8]India Meteorological Department (IMD), 2020. Observed Rainfall Variability and Changes Over Himachal Pradesh State. Issue No. ESSO/IMD/HS/Rainfall Variability/10(2020)/343. Issue Date: January 2020

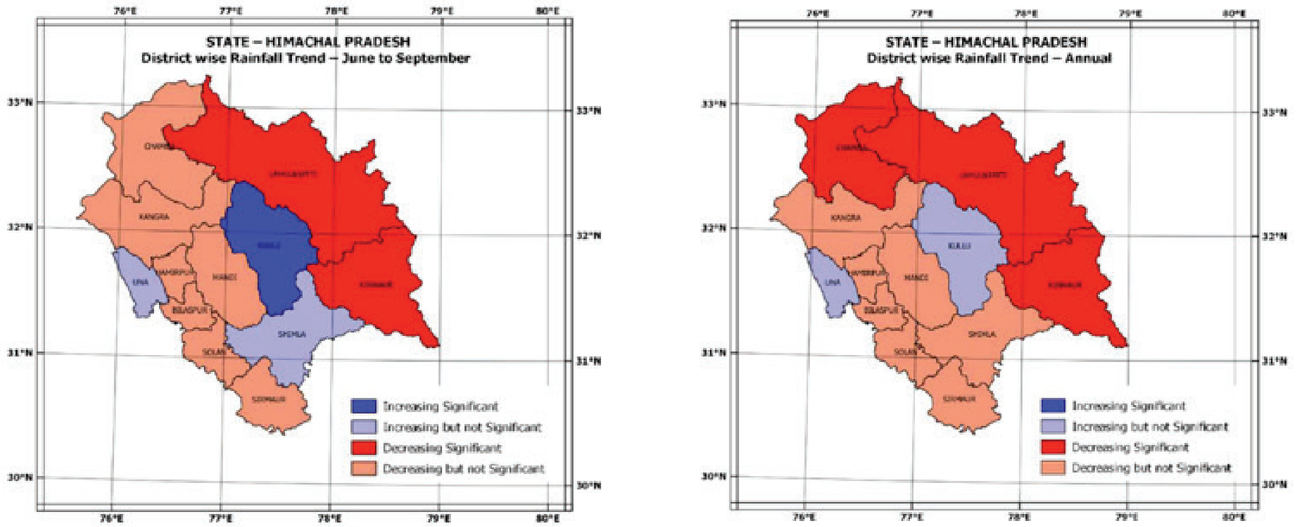


***Figure 15** Historical trends of rainfall in Himachal Pradesh. Pong Dam lake is located in Kangra district. (Source: IMD, 2020)*

3.1.2 Temperature

There are wide variations of temperature in the Pong Dam area. It ranges from 4°C during winter to 44.5°C during summer. The surface water temperature of the reservoir varies between 20°C and 40°C. Table 10 shows historical trends of the maximum and minimum temperatures observed at Palampur Kangra station (the nearest to Pong Dam) during 1985–2009. The maximum temperature increased by 0.5°C, from 31.5°C to 32.1°C, while a greater increase was observed for the minimum temperature (0.8°C).

***Table 10** Historical trends of temperature at Palampur Kangra station (the nearest to Pong Dam)*

Observation	1985	2009	Net change
Maximum temperature (°C)	31.5	32.1	0.5
Minimum temperature (°C)	4.4	5.2	0.8

(Source: Ranbir, 2010)

3.1.3 Wind

The wind at Pong Dam lake in the winter season has important ecological effects. In the morning, the wind movements are generally from the eastern to the western side and in the afternoon it blows from the western to the north-eastern direction. The lake is a huge water body that experiences rising waves depending on the wind velocity. Sometimes, the wind velocity reaches 100 nautical miles per hour.

3.2 Bioclimate zones

The map of the bioclimate zones around Pong Dam lake (Figure 16) shows that the catchment is classified as Hot and Mesic, while some of the upper catchment areas are classified as Warm and Mesic, going up to Cold and Mesic and to Extremely Cold and Mesic, in the highest elevation zones.

With climate change, there is trend of increasing rainfall in monsoon, drier dry seasons and increased temperature throughout the year. This can result in shifting of bioclimate zones around Pong Dam lake to hot and dry or even extremely hot and arid. In the upper parts of catchment, the cold nd mesic zones will shift towards cold or cold temperate and mesic zones

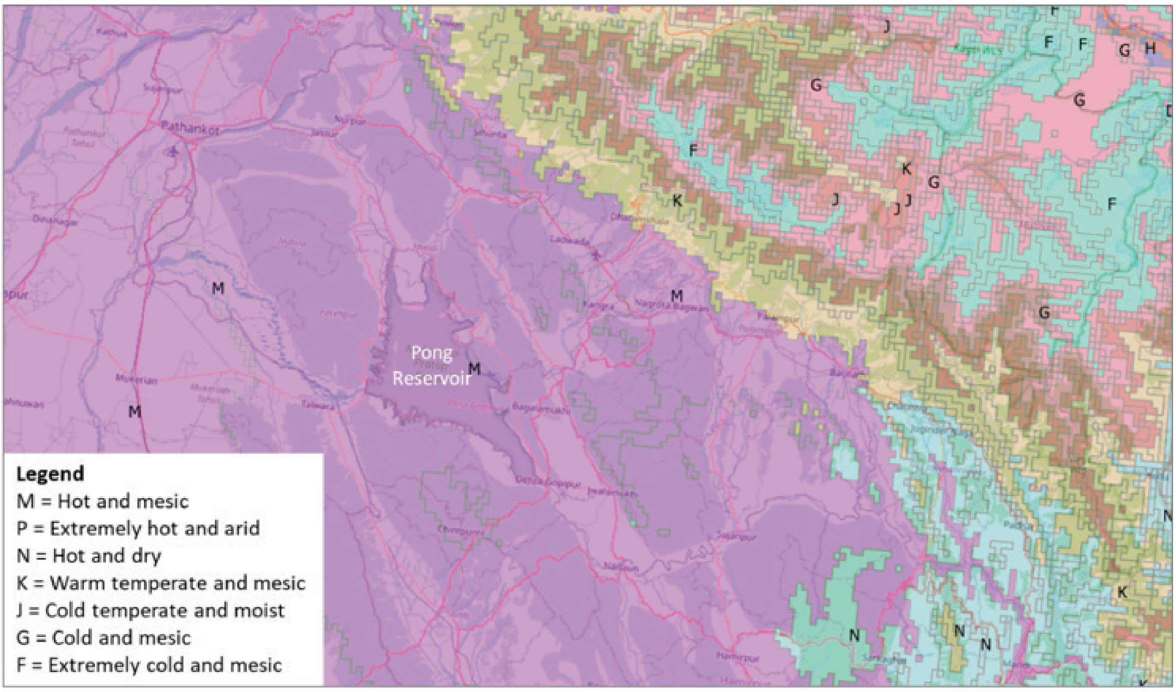


Figure 16 *Bioclimate zones around Pong Dam lake*
(Source: Adapted from Global Environmental Stratification (GEnS_v3))

3.3 Climate change projections

This section presents climate change projections (2050) for the precipitation and temperature at Pong Dam lake with respect to a baseline period of 1960–1990. These results were generated using an ensemble mean method of three selected GCMs, including CCSM4, HadGEM2-ES and MIROC-ESM, with the RCP 8.5 scenario.

3.3.1 Projections of precipitation

A summary of the precipitation projections at Pong Dam lake is shown in Table 11 and Figures 17 to 20. Overall, the total precipitation is projected to increase during the SW monsoon while decrease during other seasons.

Table 11 *Precipitation projections (for the 2050s) at Pong Dam lake (RCP 8.5)*

Season	Baseline 1960–1990 (mm)	Projection 2050s (mm)	Change (mm)	Change (%)
Winter (January–February)	170.9	152.6	-18.3	-10.7
Summer (March–May)	222.7	211.0	-11.8	-5.3
SW monsoon (June–September)	1479.8	1741.9	262.1	17.7
NE monsoon (October–December0	114.6	102.3	-12.4	-10.8

By the 2050s, the total precipitation is projected to increase by 262.1 mm (17.70%), from 1479.8 mm to 1741.9 mm, during the SW monsoon (June–September), but it is projected to decrease during the NE monsoon by 12.4 mm (or 10.8%), in winter by 18.3 mm (or 10.7%) and in summer by 11.8 mm (or 5.3%). These projections are generally consistent with results from a recent climate change assessment for the Pong Basin conducted using CORDEX South Asia RCM[9] (see Annex 2 for more details).

[9]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

More significant changes in precipitation (i.e., increasing during SW monsoon and decreasing during other seasons) are projected for zones immediately upstream of the Pong Dam lake. This may lead to higher risks of flash flooding, increasing the turbidity in the reservoir, and extreme floods and storms. Lower rainfall in the dry season may cause intensive droughts in the Pong Dam lake and surrounding areas and negatively affect the ecology of the Ramsar site.

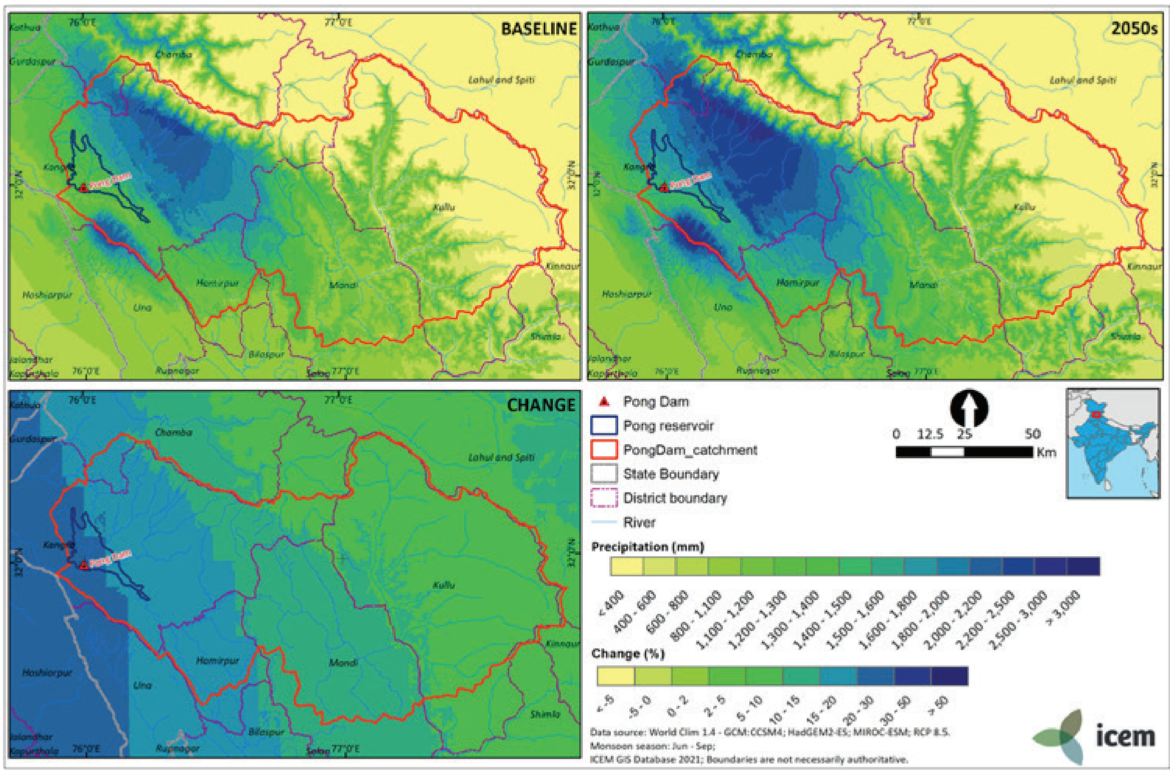


Figure 17 *Projections of precipitation during the SW monsoon (June–September) for Pong Dam lake basin (RCP 8.5)*

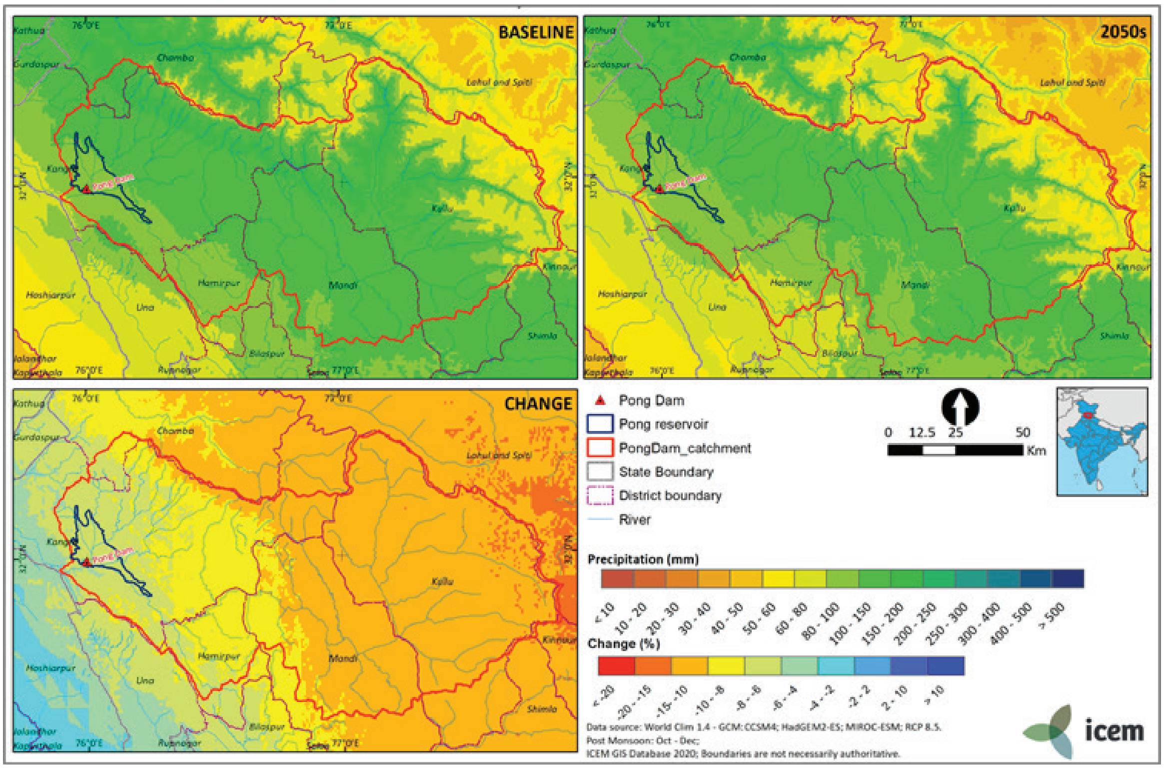


Figure 18 *Projections of precipitation during NE monsoon (October–December) for Pong Dam lake basin (RCP 8.5)*

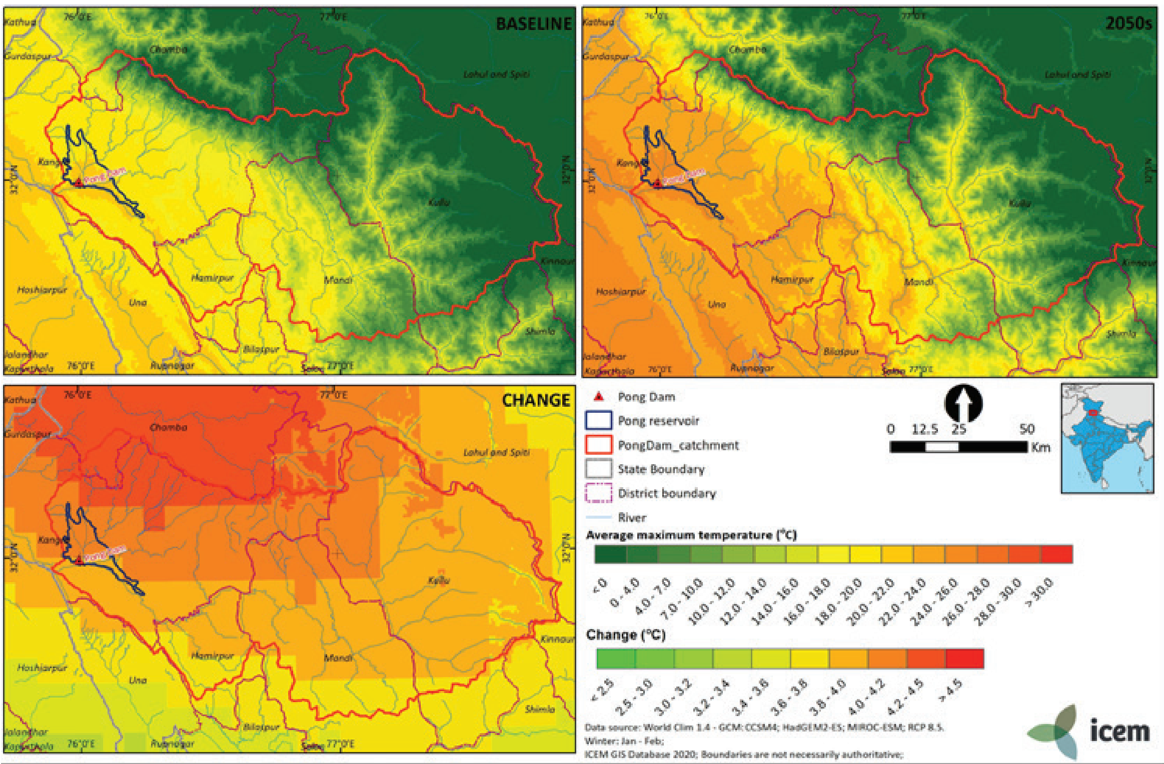


Figure 19 *Projections of precipitation during winter (January-February) for Pong Dam lake Basin (RCP 8.5)*

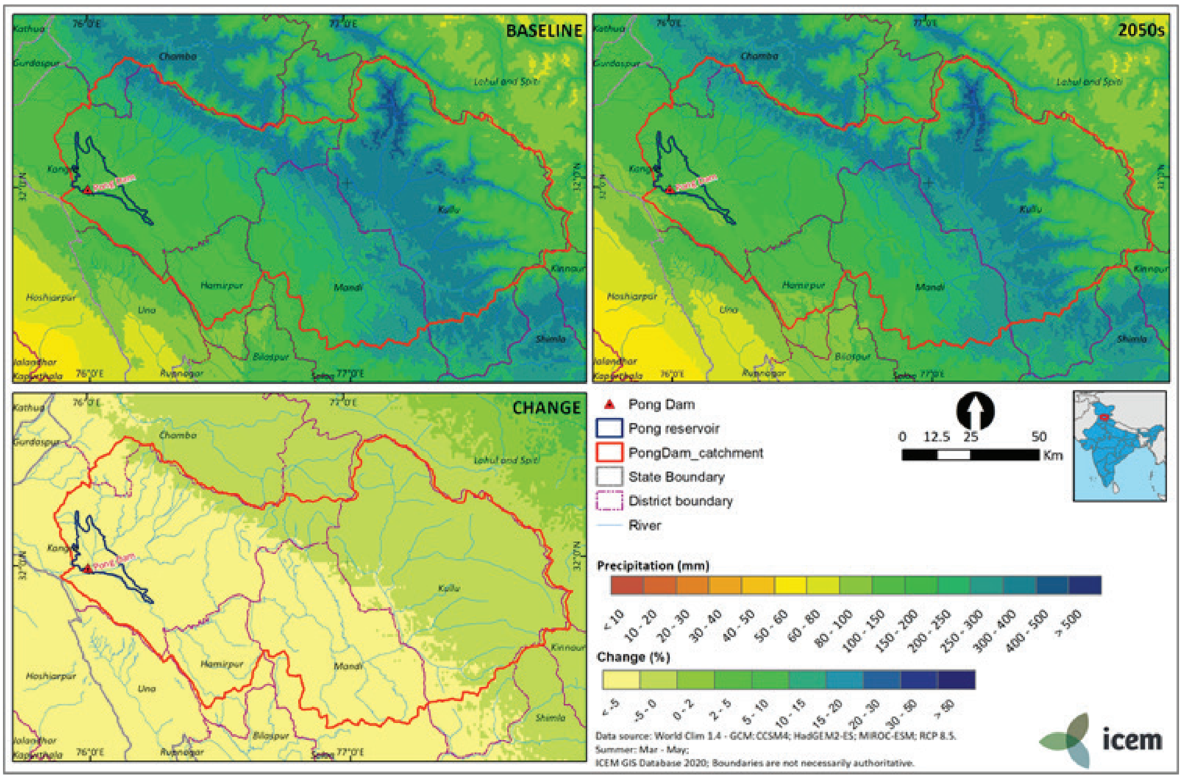


Figure 20 *Projections of precipitation during summer (March–May) for Pong Dam lake Basin (RCP 8.5)*

3.3.2 Projections of temperature

Projections of the average maximum temperature and its changes by 2050 at the Pong Dam lake, with respect to the baseline period of 1960–1990, are shown in Table 12 and Figure 21. Overall, the average maximum temperature is projected to increase significantly by 1.8°C to 3.3°C. These projections are generally consistent with results from a recent climate change assessment for the Pong Basin conducted using CORDEX South Asia RCM[17] (see Annex 2 for more details).

The most significant increases are projected for the monsoon seasons, with an increase of 3.1°C for the SW monsoon (from 24.1°C to 27.2°C) and of 3.3°C for the NE monsoon (from 15.6°C to 18.9°C). The winter months (January–February) are projected to be warmer, with an increase in the average maximum temperature by 2.8˚C (from 9.60˚C to 12.40˚C). The average temperature during summer is also projected to increase by 1.8˚C (from 23.9˚C to 25.7˚C). These are very significant changes that are certain to lead to ecological stresses and shifts, including changes in the species composition and populations, higher evaporation and lower reservoir water levels.

Table 12 *Average maximum temperature projections for the 2050s at Pong Dam lake (RCP 8.5)*

Season	Baseline 1960–1990 (°C)	Projection 2050s (°C)	Change (°C)
Winter (January–February)	9.6	12.4	2.8
Summer (March–May)	23.9	25.7	1.8
SW monsoon (June – September)	24.1	27.2	3.1
NE monsoon (October–December)	15.6	18.9	3.3

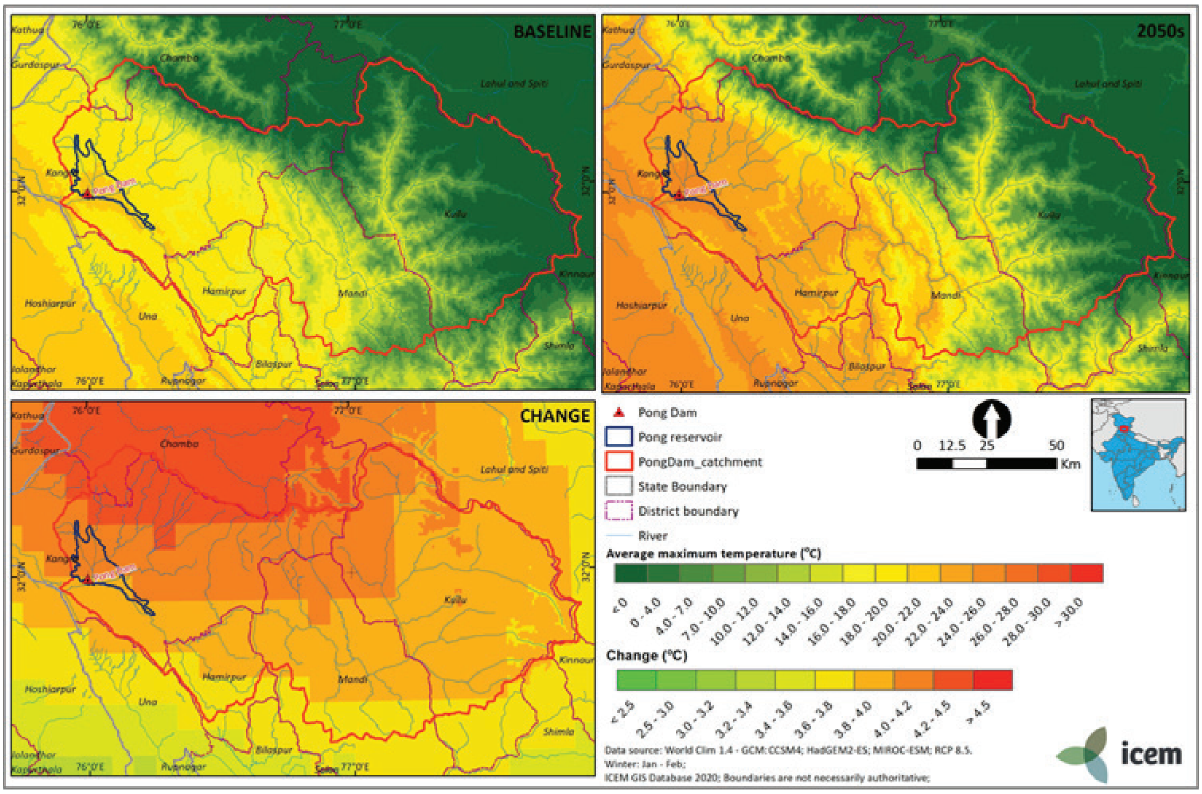


Figure 21 *Projections of maximum temperature during winter (January–February) for Pong Dam lake basin (RCP 8.5)*

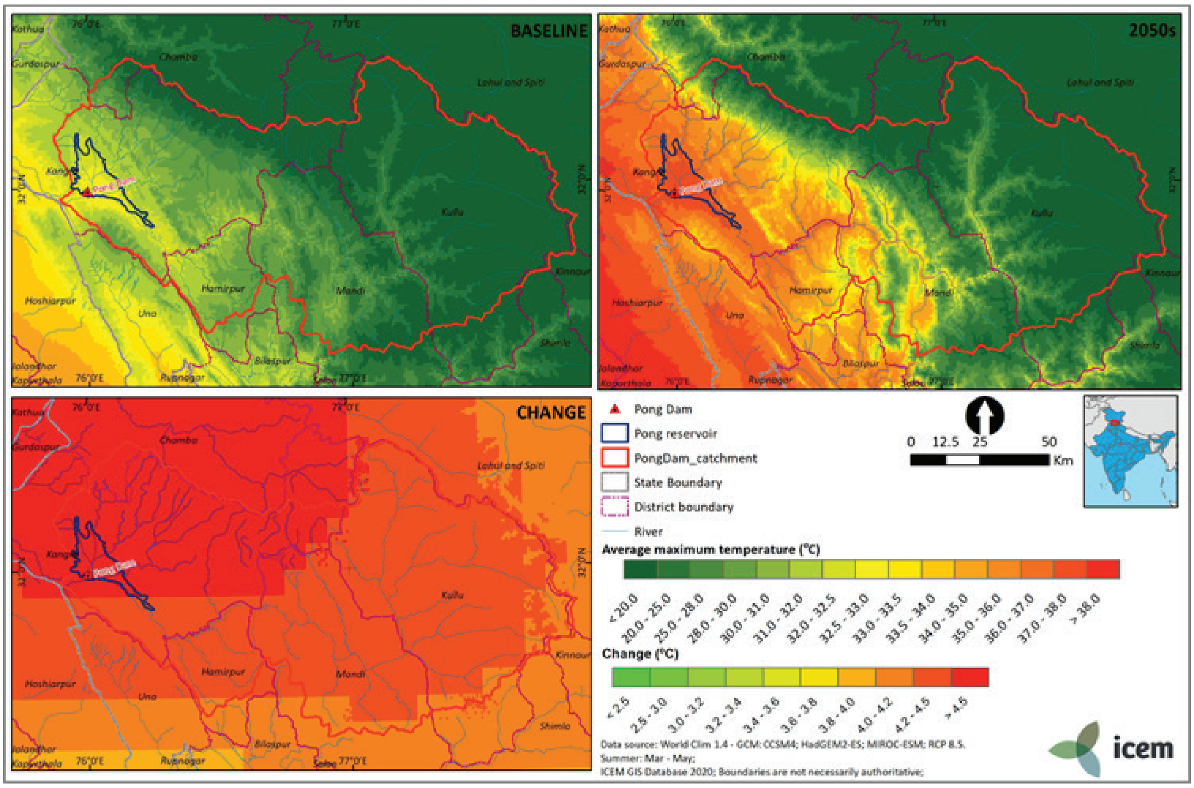


Figure 22 *Projections of maximum temperature during summer (March–May) for Pong Dam lake basin (RCP 8.5)*

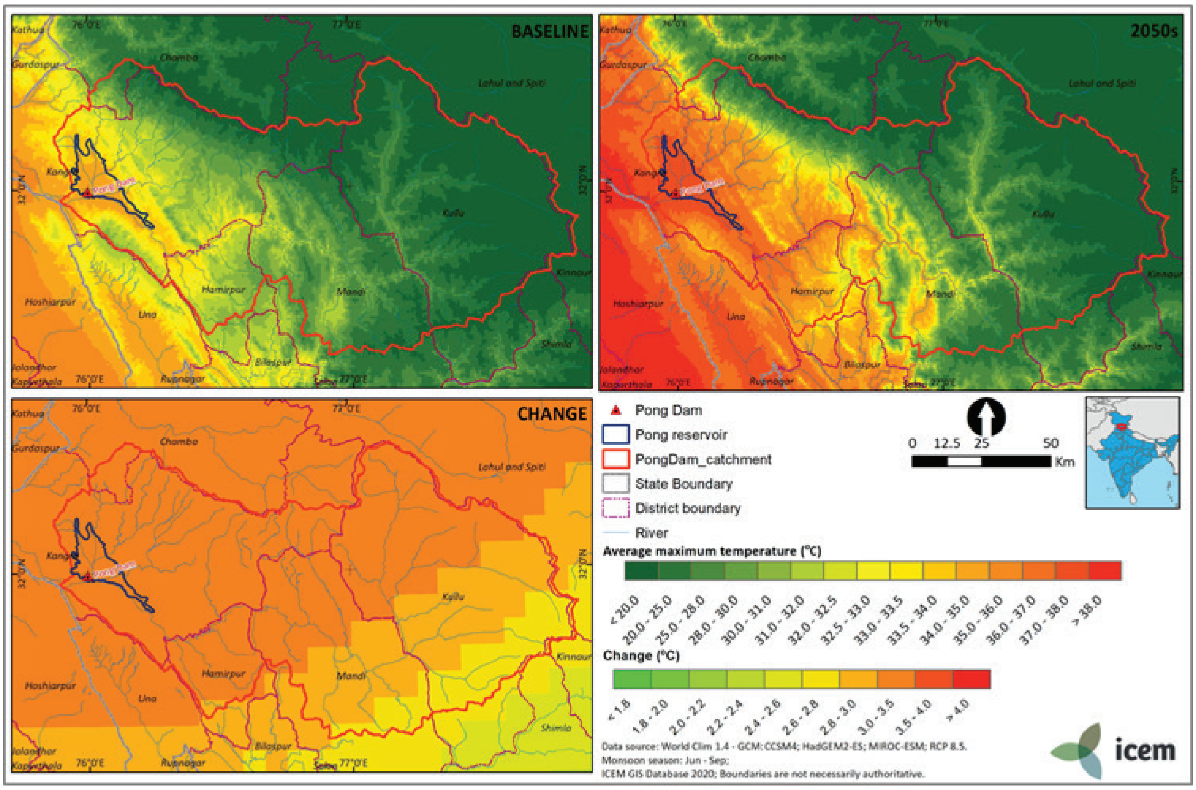


Figure 23 *Projections of maximum temperature during SW monsoon (June–September) for Pong Dam lake basin (RCP 8.5)*

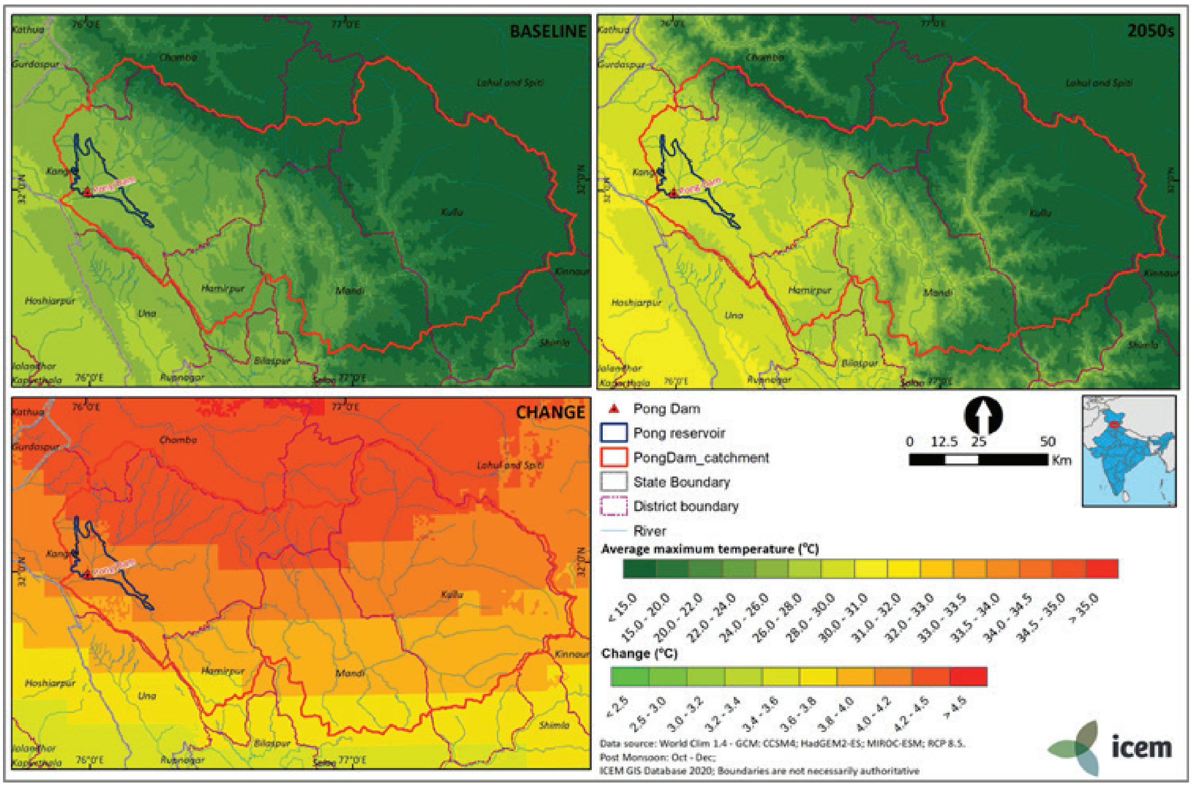


Figure 24 *Projections of maximum temperature during NE monsoon (October–December) for Pong Dam lake basin (RCP 8.5)*

3.3.3 Projections of extreme events

Heavy and very heavy precipitation days (R10mm and R20mm) are projected to increase in Pong Dam lake towards the 2050s compared with the baseline period (1960–1990). Consequently, very wet days and extremely wet days will increase in Kangra district. Consecutive dry days and wet days are also projected to increase, as are high wind events and wind speed during the NE monsoon and winter. Results of the assessment indicate that the percentages of cool nights and cool days will decrease while warm nights and warm days will increase.

The increase in precipitation will contribute to the streamflow and baseflow, with a marginal reduction in evapotranspiration and changes in rainfall distribution. Similarly, the increase in precipitation is likely to return as groundwater recharge. The streamflow and groundwater recharge are projected to increase in all the districts.

4 IMPACT AND VULNERABILITY ASSESSMENT

4.1 Vulnerability overview of Pong Dam lake

This section summarises the overall vulnerability of the Pong Dam lake, on the basis of the more detailed assessments of the target assets: the catchment, hydel project, reservoir, migratory bird habitats, key species (Bar-headed Goose, Northern Pintail and Golden Mahseer) and livelihoods (fisheries). The summarised VA matrix for these assets are shown in Figure 25. The Vulnerability Assessment Matrix for each asset is attached as complementary material to this report (a list of files is shown in Annex 3).

From a Ramsar site perspective, the key feature of the Pong Dam lake is its ecosystem health and attractiveness for the large numbers of migratory birds visiting each year and the fish species and productivity of the reservoir. Without these, the area would be simply another large man-made reservoir and the focus of the vulnerability assessment would be different – perhaps on the functioning of the hydel plant.

The most important climate change threats to Pong Dam lake and the reservoir are an increase in rainfall during the monsoon by 17.7% and a more significant increase in areas immediately upstream in the catchment, which will be combined with an increase in the frequency and magnitude of flooding, glacial melt and risk of GLOFs. There will be a substantial decrease in rainfall during the winter, by 10.7%, with increasing consecutive days of drought and an increase in the average temperature by 2.8°C, 1.8°C and 3.3°C during winter, the pre-monsoon season and the post-monsoon season, respectively.

The increase in rainfall and flash flooding during the monsoon is likely to increase the soil erosion in the catchment and sediment deposition in the reservoir. Sedimentation in the reservoir is already an issue of concern because most of the sediment is deposited in the active storage volumes of the reservoir around the shallow drawdown areas forming deltas where the *khads* flow into the reservoir. These are the areas favoured by the roosting and feeding migratory birds. Increased sediment deposition will change the ecological character of these areas, smothering the bed and aquatic vegetation on which the birds feed.

The changes in the hydrology of the lake and potential increase in flooding are concerns both to the operators of the hydel plant and the managers of the Ramsar Site. Although the Pong Dam lake offers a considerable degree of regulation of the Beas river, the ability of the management of the hydel plant to cope with changes in regular flows and extreme flooding is constrained by the demand for irrigation water and power generation. With the future increase in rainfall, filling of the reservoir may occur more rapidly during the monsoon meaning that spillways will have to be operated earlier to pass the more frequent floods downstream. In the rest of the year, the hotter temperatures and increased number of drought days will increase the demand for irrigation water, so the drawdown of the reservoir is likely to be more rapid. The changing hydrological patterns of the fill and drawdown of the reservoir will also change the ecological character of the reservoir. It is not known how this will affect the habits of the migratory bird, but it is known that the fish production is dependent on the period of high water levels in the reservoir.

The attractiveness of the Pong Dam Lake area for migratory birds depends on the safety of the roosting areas for large numbers of water birds and the availability of food sources for the birds to gain strength and recover from their flights over the Himalaya before they fly further south. This assessment does not cover the vulnerability of the birds at their breeding sites in Central Asia, although in the future increasing temperatures in southern destinations may cause larger numbers of migratory birds to overwinter at Pong Dam lake.

The continued provision of adequate food sources for the migratory birds will depend on the ecological and productivity shifts within the aquatic environment, particularly the shallow waters where the dabbling ducks such as the Northern Pintail feed on aquatic vegetation, invertebrates, the terrestrial vegetation and crops grown in the drawdown area and surrounding the reservoir, where the Bar-headed Geese and lapwings feed. The combination of increased temperatures and decreased rainfall and drought during the winter and hot seasons will change the species suitability, cropping patterns and productivity of these areas, making provision of adequate food sources uncertain.

Increased reservoir water temperatures throughout the year, but especially during the hot and pre-monsoon seasons, may change the water quality, decreasing the DO content, which trend is already being noted. It is possible that the increased surface water temperatures will give rise to the stratification of deeper parts of the reservoir. This will carry an increased risk of overturning, bringing anaerobic waters to the surface from the bottom at certain times of the year and causing fish mortality, e.g., in autumn, when the winds create turbulence. Increased sediment coming down the rivers during the monsoon is also likely to increase turbidity in the reservoir. The changing water quality is likely to affect the fisheries, favouring warm-water species at the expense of colder water species such as the Golden Mahseer, although the increased rainfall during the monsoon may make it easier for the spawning migrations of this species up the rivers and streams.

Threats	Catchment					Reservoir					Pong Dam Hydel				
	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul
Precipitation															
Increase of rainfall during Monsoon (Jun–Sep)	H	M	H	H	M	VH	H	VH	M	VH	H	L	M	H	M
Decrease of rainfall during Winter (Jan-Feb)	H	M	H	M	H	H	M	H	M	H	H	M	H	L	H
Temperature															
Increase of temperature during the hot season/Monsoon (Jun–Sep)	VH	H	VH	L	VH	VH	H	VH	L	VH	VH	H	VH	L	VH
Increase of temperature during the cold season (Oct–May)	H	H	H	L	H	M	M	M	L	M	H	H	H	L	H
Extreme events															
Flood	H	M	H	H	M	H	M	H	M	H	H	M	H	H	M
Flash flooding						L	L	L	H	L					
Drought	M	L	M	M	M	H	H	H	M	H	M	L	M	M	M
Wind	L	L	L	H	L	H	M	H	M	H	L	L	L	H	L

Threats	Migratory bird habitats					Bar Headed Geese and Northern Pintail					Golden Mahseer					Fisheries				
	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)	VH	M	VH	M	VH	VH	M	VH	M	VH	H	M	H	M	H	H	M	H	H	M
Decrease of rainfall during Winter (Jan-Feb)	H	M	H	M	H	H	M	H	M	H	L	L	L	M	M	H	L	M	M	M
Temperature																				
Increase of temperature during the hot season/Monsoon (Jun–Sep)	VH	H	VH	L	VH	VH	H	VH	L	VH	H	H	H	L	VH	H	H	H	L	H
Increase of temperature during the cold season (Oct–May)	H	H	H	L	H	H	H	H	L	H	M	M	M	L	M					
Extreme events																				
Flood	H	H	H	M	H	H	H	H	M	H	H	H	H	M	H	H	M	H	M	H
Flash flooding	L	L	L	H	L	L	L	L	H	L										
Drought	L	L	L	M	M	L	L	L	M	M	H	H	H	L	H	H	H	H	L	H
Wind	H	M	H	VL	VH	H	M	H	M	H						H	M	H	VL	VH

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

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

***Figure 25** Summary Vulnerability Assessment matrix for Pong Dam lake and its assets*

4.2 Catchment

Asset description: Pong Dam lake is a reservoir located in Kangra district, Himachal Pradesh and has a catchment area of 12560km². This reservoir covers an area of 245.29 km², with a wetland portion of ~156.62 km² (Pathania et al. 2017). The Beas is the major river that drains the catchment, along with its tributaries the Parvati, Sainj and Tirthan.

EXPOSURE

The main climate risks to which the catchment is exposed are the increased rainfall during the monsoon and the increased temperature during the hot season, both of which are likely to increase the risks of flash flooding. The rainfall during the monsoon period is expected to increase by 19%, with greater intensity rainfall being experienced during storm events. The increased rainfall is expected to increase soil erosion in the catchment, which is already degraded, and cause landslides in the steeper, less stable hillsides. Forest fires induced by high temperatures during the dry season are likely to further degrade the area.

The increased temperatures during the monsoon are expected to increase the rate of snow melt and retreat of the glaciers, with increased risks of GLOFs in the upper catchment, causing major flooding events downstream of the Beas river, even up to the Pong Dam lake.

SENSITIVITY

The presence of a large number of overhanging cliffs and steep slopes make this catchment very sensitive to topographical and climatic changes (Emmer et al., 2016). A large number of glacial lakes and recent changes in their number and size (Dubey & Goyal, 2020) have increased their sensitivity. The watershed is fed by rivers that are snow melt-dependent. Retreating glaciers can significantly alter the discharge pattern (Azam et al., 2021). The lower catchment is highly sensitive to soil erosion because it has been progressively degraded by deforestation and traditional agricultural practices that do not conserve the soils. Increased population, urbanisation, rapid development and tourism activities have also increased the sensitivity of the catchment to climate changes.

IMPACTS

In the upper catchment, glaciers are retreating and developing new glacial lakes, which can cause devastating flash floods throughout the catchment, down to the reservoir. Increased flooding events will also trigger more and larger landslide and avalanche events.

The main impact of these climate change risks is an increase in soil erosion in the whole catchment, with greater quantities of sediment being washed down the Beas river and *khads* into the reservoir. This will lead to reduced water quality and sedimentation in the active storage areas, where the rivers form deltas as they flow into the reservoir. These shallow areas are preferred by the migratory ducks and geese for feeding and roosting.

Industrial and tourism activities and urbanisation are also causing poor water quality and increased nutrients, potentially leading to eutrophication in the reservoir.

ADAPTIVE CAPACITY

The catchment has a 'very low' adaptive capacity as it is not possible to stabilise each slope that can trigger landslides. Most of the glacial lakes are inaccessible, and it will be very difficult to monitor them and take precautionary measures. Flooding events in the upstream portion of the catchment cannot be managed without appropriate infrastructure, and the upstream Pandoh Dam does not have a sufficient storage capacity. The catchment requires additional forestation and soil conservation measures.

VULNERABILITY

The catchment is assessed as being 'highly vulnerable' to increased rainfall and increasing temperatures, especially during the monsoon, giving rise to increased risks of flash flooding and soil erosion. The risks of snow melt and GLOFs in the upper catchment are likely to exacerbate the vulnerability to flooding and sedimentation in the reservoir.

4.3 Pong Dam Hydel

Asset description: The stored water is primarily used for meeting irrigation water demands, for which a total of 7913 Mm3 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.

EXPOSURE

The Pong Dam hydel project will be highly exposed to the expected climate change trends, i.e., a rise in temperature, an increase in consecutive drought days, an increase in rainfall during the monsoon, followed by a decrease in the winter and pre-monsoon rainfall and an increase in flood risk. The services provided by Pong Dam lake, such as irrigation, power generation and flood control, will be affected. The increase in rainfall during the monsoon will change the hydrological regime of the reservoir, and the increase in temperature and decrease in rainfall during the hot pre-monsoon seasons will increase the demand for irrigation water downstream. Increased temperatures in the dry season will increase the evaporation from the reservoir surface, resulting in more rapid drawdowns. With an increased flood risk, the operation of the spillways and gates will become more important for flood management.

SENSITIVITY

The Pong Dam hydel project is highly sensitive to the rise in temperature during the hot season/monsoon (June–September) and cold season (October–May). The downstream irrigated areas are sensitive to increases in temperature, which will increase the demand for water to be released during the hot season. More warm days will increase the evapotranspiration and will lead to less power generation. Also, the marked increase in average maximum temperatures could adversely affect the working of hydraulic structures, including turbines.

IMPACTS

The overall impact levels suggest that the expected climate change trends, i.e., a decrease in the rainfall during winter, a rise in the temperature during the monsoon and winter and an increased flood risk, will have a high to very high impact on this asset. The following impacts on Pong Dam are identified:

- The increased rainfall in the catchment during the monsoon will contribute to an increase in the annual water balance of over 200 mm per annum. The extent to which this can be utilised to increase power generation and downstream irrigation will depend on the storage capacity within the reservoir.

- During the dry season, the decreased rainfall and hotter temperatures will increase the demand for irrigation water, which may not be entirely offset by the increased rainfall during the monsoon. Lowered reservoir levels during the winter and pre-monsoon will reduce the availability of water for irrigation downstream and the potential for hydropower generation.
- Due to the decrease in rainfall and increase in consecutive drought days, the lower water levels in the reservoir and low soil moisture are likely to affect irrigation and the vegetation cover in the drawdown areas. The arable winter crops grown around the lake, which are dependent upon the drawdown, may become less productive.
- Due to the high daily difference in temperature between the surface and near-surface areas of the dam, surface cracks may develop. Cracks adversely affect water tightness and durability and therefore, are undesirable.
- Surface water temperature increases will result in evaporation losses and impact the operation of hydraulic machines. Hydraulic machines may need cooling at higher-temperature conditions and may require additional investments.
- Increased wind action and high waves could lead to an increase in evapotranspiration and damage or reduce the life of hydraulic equipment.

ADAPTIVE CAPACITY

The adaptive capacity of the Pong Dam hydel plant to the exposure to changing hydrological patterns is 'moderate' because the plant has been designed to regulate the flows in the river according to both the inflows from the catchment, the storage capacity and the demand for irrigation downstream. There is some flexibility in the patterns of filling and drawdown of the reservoir to allow for increases in rainfall in the monsoon and the increased demand for irrigation water during the hot season and pre-monsoon during droughts. However, this adaptive capacity is constrained by the storage volume available and the pressures to provide irrigation and domestic water for downstream users.

Pong Dam lake has a 'low' adaptive capacity to rising temperatures in the hot season and winter as both the structures and hydraulic equipment were not designed for the projected increases.

VULNERABILITY

Pong Dam lake is 'highly vulnerable' to the changing hydrological patterns caused by increased rainfall in the monsoon with the potential for floods, and the decrease in rainfall during winter. It has a high to 'very high 'vulnerability to the rise in temperature during both winter and summer seasons.

4.4 Pong Reservoir

Asset description: This reservoir has an area of 24,529 ha, and the wetland portion is ~15,662 ha. The reservoir is 42 km long, with a maximum width of 19 km, and has a mean depth of 35.7 m. The surface water temperature of the reservoir varies between 22.2°C and 25.1°C. The monsoon rainfall between July and September, along with snow melt, is the major source of water. The habitats in the reservoir area consist of open deep water with shallow water in the drawdown area, which dries to uncover dry sandy banks with little or no vegetation. Waterside vegetation and swamps occur below the regulating/diversion pond after the dam, making important habitats for migratory and resident birds.

EXPOSURE

The increased rainfall during the monsoon will lead to a positive change in the water balance of the reservoir, but the risks of drought and lower rainfall during the dry seasons are likely to lead to a higher demand for irrigation water from the downstream states served by the Pong Dam irrigation system, leading to a more rapid fall in the water level in the reservoir. The risks of flood water entering the reservoir due to storm events in the catchment or even an extreme event such as a GLOF could damage the reservoir habitats and be passed on to downstream habitats. High intensity rainfall is likely to increase soil erosion and could trigger landslides carrying excess sediment into the reservoir.

Increases in the air temperature in all seasons will lead to increases in surface water temperature, which could become important in the hottest pre-monsoon periods. The wind at certain times of year such as in the early winter period is likely to increase, causing large waves and turbulence on the surface of the reservoir.

SENSITIVITY

The lake water levels are highly sensitive to increases in temperature, decreases in rainfall and drought in the command areas of the irrigation system, e.g., in other states such as Rajasthan, which will lead to an increase in demand for discharges from the Pong reservoir. The interdependence between the climate patterns in other states and the reservoir level in Pong makes a complex and sensitive system (Soundharajan et al., 2016).

Sedimentation and turbidity in the lake are already issues of concern. Increasing soil erosion in the catchment will increase sedimentation rates. Sediment is likely to accumulate in the shallower active storage volumes of the lake, tending to reduce its capacity.

Increases in the temperature of the surface water of the reservoir will exacerbate water quality issues, which have already become impaired by upstream industrialisation, urbanisation and tourism activities. There are also concerns about increases in the quantities of pesticides reaching the reservoir due to changes in cropping patterns in the catchment.

IMPACTS

The changing patterns of filling and drawdown of the reservoir, resulting from increased rainfall in the monsoon, followed by increased demands for water for irrigation and domestic water supply downstream during the drier months and pre-monsoon season, will result in more rapid movements of the water levels in the reservoir, changing its hydro-ecological character, with implications for species and habitats.

Flash floods and risks of landslides and GLOFs are likely to damage the reservoir habitats, either washing out some areas adjacent to the deltas where the Beas river and the ***khads*** meet the reservoir or washing-in excess sediment into these areas. The sediment will likely accumulate in the shallower parts, reducing the active storage capacity of the reservoir and covering the productive substrate used by the migratory ducks and geese and the spawning areas of fishes.

As an upstream run-of-river dam, Pandoh hydel project will provide little protection from large flash flood events, though it may trap some of the bed load of the sediment washed down from the upper catchment.

The more rapid rate of drawdown of the water levels during the winter and hot season due to the demand for irrigation water downstream may impair the local recession agriculture around the reservoir, which is dependent on a slower drawdown.
The increase in surface water temperature during the hot season could exacerbate water quality issues by encouraging algal blooms, with the excess nutrients flowing into the reservoir from urban areas and agricultural areas. The higher surface water temperatures could lead to stratification in the deepest parts of the reservoir, with the lower levels becoming oxygen depleted. Turnover events that may occur with flash flows of colder water during the monsoon or strong winds at the beginning of the winter period could cause poor quality water reaching the surface, with fish mortality in the reservoir and downstream.

ADAPTIVE CAPACITY

The reservoir levels are managed according to the demand for irrigation water and power, and so the water management structures at Pong Dam lake provide a ‘medium’ level of adaptive capacity. The spillway gates can be adjusted to reduce the flood risk. Dredging can also be carried out to reduce sedimentation (Annandale, 2006) although this is a tedious task in a lake of such high sediment and active storage volumes.

VULNERABILITY

The interdependence of increased sedimentation and high evaporation losses in the reservoir make it highly vulnerable to increased temperatures and changing patterns of precipitation, just as it is to critical events such as flooding and droughts.

4.5 Migratory bird habitats

Asset description: Pong Dam and Pong Reservoir are located on the flyway of migratory birds and are ideal for roosting and resting after migration across the Himalaya. The most important habitats for migratory birds are found at Nagrota Surian, in the North-Eastern corner of Pong Dam lake (Kumar and Kumar, 2012), and at the delta shorelines of the inflowing *khads.* These sites provide a natural habitat with flat shallow areas and mudflats that retain aquatic plants and rhizomes for the birds to feed on. They are also adjacent to agricultural lands where waterfowl feed on crop residues. In addition to the strategic location of Pong Dam and Reservoir on the flyway immediately after the high migration flights across the Himalaya, the access to safe roosting sites and the availability of food for the different species of migrating bird make Pong Dam an attractive staging area for winter migrants.

EXPOSURE

The projected increase in temperature during the cold/hot seasons will tend to shift the bioclimate from hot and mesic towards hot and arid in the area, which may reduce the attractiveness of Pong Dam lake for migratory birds. Shallow mudflats, which are usually the roosting and feeding grounds for migratory birds, are sensitive to the changing climate as the increase in temperature and hydrological changes can shift the shorelines of the reservoir and alter their spatial extent (DeGraaf & Rappole, 1995).

The decrease in rainfall during the winter months, along with increased temperatures, will increase the evapotranspiration and result in greater seasonal aridity, making the area less suitable as a migratory bird habitat. The increase in rainfall and flash flooding during the monsoon season will quickly increase water levels to the full supply level in the reservoir, but the more rapid drawdown during the winter months will maintain open spaces for roosting migratory birds. Increases in soil erosion in the catchment and sediment deposition in the reservoir are likely to result in the shifting of mudflat zones and aquatic plants, altering the birds' feeding areas.

Due to the projected increase in high wind events in post-monsoon and winter seasons, winds blowing across the reservoir from the southwest towards the preferred roosting areas may disturb migratory birds causing them to move to other locations in the lake. The winds blowing across the huge open water of the lake may cause waves and erosion of the shoreline where the birds roost.

SENSITIVITY

The migration patterns of these migratory birds are highly sensitive to the expected climate change trends. For this assessment, we are considering the changes in the attractiveness of Pong Dam lake for migratory birds – their roosting and feeding habitats – which will affect the numbers of migratory bird visiting the area from October to March. We are not assessing the influences of climate change upon the summer breeding sites to the north and breeding success, which will probably have greater impacts upon the overall population numbers.

The increase in temperature may cause the migratory birds to experience unprecedented temperatures and weather conditions. The impacts of exposure to such climatic conditions are still unknown. Yet, previous studies have suggested that the projected changes can be threatening to some species (Newson et al., 2009). The migratory behaviour of the birds is not predictable, but it may be that increases in the cold season temperatures will shift their behaviour, with greater numbers remaining at Pong Dam lake rather than moving to the south, where the temperatures will be even higher.

During the hot season at Pong Dam lake, when the migratory birds are not present, the increase in temperature and evapotranspiration is likely to affect the riparian and terrestrial vegetation, causing changes in productivity and species shifts. The shallow water habitats around the reservoir will warm up, which might affect the aquatic vegetation and phytoplankton, and thus bird food resources once they arrive. Rising temperatures in the cold season and the shifting of the spring season may lead to changes in the availability of aquatic plants, crops and terrestrial vegetation on which the migratory birds depend.

Due to the expected increase in the frequency of flash flooding, the resulting erosion will lead to increased sedimentation in the reservoir. This may result in the covering of the mudflat zones with less productive sediment, extending the shallow areas towards deeper parts of the reservoir, and changing the habitat of migratory birds, potentially making them less attractive.

IMPACTS

All the climate change trends considered except flash floods and droughts impact the migratory birds and their habitats at the Pond Dam lake as follows:

- The increase in temperatures during the winter may make Pong Dam lake a more attractive area to overwinter in compared with the hotter migration areas to the South, and so greater numbers of birds will remain on the site. This in turn will put greater pressure on the food resources available for the birds.
- Increased erosion in the catchment leads to increased sediment loads in the reservoir, smothering aquatic plant habitats and shifting mudflat zones.
- The increased temperatures and catchment erosion could reduce productivity of aquatic plants, terrestrial vegetation and crop residues available as feed for migratory birds.
- The shallow water areas in the drawdown of the reservoir available for migratory birds to feed in will be changed or reduced.
- Wind and wave erosion of the North-Eastern shore and shifting of mudflat zones could reduce roosting areas for migratory birds.
- Wind and wave disturbance of migratory birds, especially on the north-eastern shore in afternoons, might lead to shifting of birds to bays that are more sheltered but are less secure from predators and hunting.
- Extreme weather conditions such as floods and droughts in the region can alter the available agricultural products in the nearby areas, thereby affecting the availability of food.

ADAPTIVE CAPACITY

Part of the adaptive capacity of migratory birds is to find the most suitable staging posts and destinations for their southward migration in October and northward migration in March. They will move around in search of the most attractive locations that provide roosting security and available food supplies to provide energy for onward migratory flights. The continued attractiveness of Pong Dam lake for migratory birds depends on the adaptive capacity of the habitats. The regulation of the water levels in the dam provides a medium adaptive capacity to changes in rainfall and flooding, but the adaptive capacity of the habitats to increased temperatures and droughts during the winter period, when the birds are present, is ‘low’ if there is less food available. In addition, there is a ‘very low’ adaptive capacity to the disturbance and erosion of strong winds.

VULNERABILITY

The migratory bird habitats and their ability to provide secure roosting areas and access to sufficient food resources are ‘highly vulnerable’ to most of the expected climate change threats. The habitats have a very ‘high vulnerability’ to the increase in temperature during winter and monsoon seasons, and a ‘high vulnerability’ to the projected increase in rainfall and flooding during the monsoon even though the birds will not be present at that time. The habitats are also ‘highly vulnerable’ to the decrease in rainfall during winter due to changes in the availability of food. Shallow water zones, swamps and marshes are especially ‘vulnerable’ to prolonged dry seasons, which can significantly change the character and productivity of these areas.

4.6 Bar-headed Geese and Northern Pintail

Asset description: Bar-Headed geese and Northern Pintails are seen in large migratory congregations in this wetland. More than 45% of the world’s population of Bar-headed Geese visits this site. Bar-headed Geese are herbivores (graminivores, granivores) and feed mainly on grasses around the lakes where they nest. In overwintering habitats, they also eat corn, barley, rice, wheat and occasionally molluscs, insects and crustaceans. Northern Pintails feed by dabbling and upending in shallow water for plant matter mostly in the evening or night (Madge & Burn, 1988). These two species have been selected as representative assets because of their different feeding habits.

In 2019–20, the total count of Bar-headed Geese at the lake was 29,443, while in 2021, 49,496 geese visited the lake, compared with 2018–19, when the total count was 17,934 (Kumar, 2019). Bar-headed Geese breed in summer in high-altitude lakes up to 4000–5000 m in Central Asia, where the bird grazes on short grass (Figure 24). They migrate to South Asia by crossing the Himalaya in October. The Northern Pintail has a wide geographic distribution, breeding in the northern areas of Europe and across the Palearctic and North America. It is migratory and winters south of its breeding range to the equator (Figure 25).

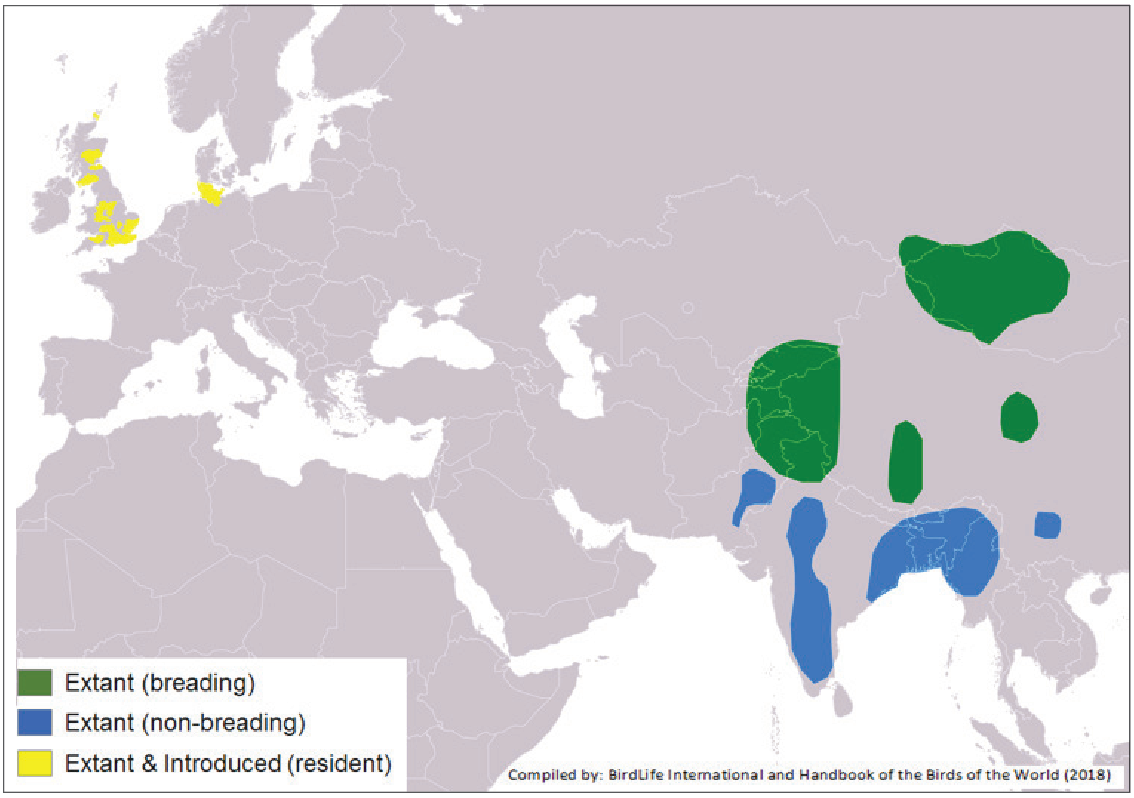


Figure 26 *Breeding and overwintering ranges of the Bar-headed Goose (Source: IUCN version 2020.3)*[10]

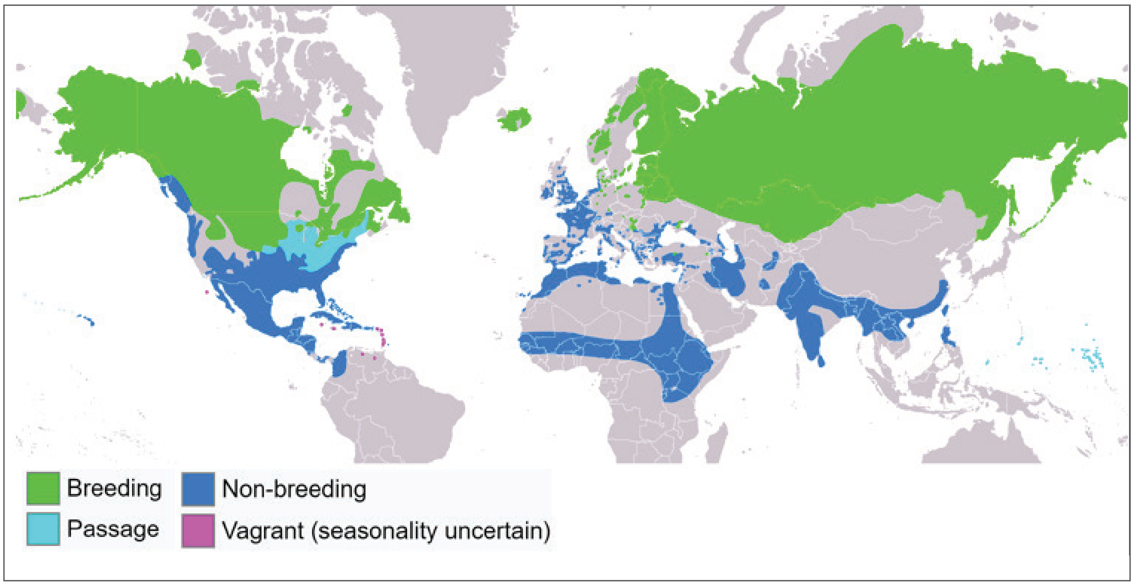


Figure 27 *Breeding and overwintering ranges of the Northern Pintail (Source: IUCN version 2019-2)*[11]

[10]Adapted from https://en.wikipedia.org/wiki/Bar-headed_goose#/media/File:AnserIndicusIUCN.svg
[11]Adapted from https://en.wikipedia.org/wiki/Northern_pintail#/media/File:AnasAcutaIUCN2019_2.png

EXPOSURE

The key exposure period of these two migratory birds is between October and March, when they will visit the site in large numbers. The projected climate change trends i.e., rise in temperature, increase/decrease in rainfall during monsoon/winter, increase in flood risk and more intense wind events, were found to substantially increase the exposure of the Bar-headed Geese and Northern Pintails. The increase in rainfall/flooding during the monsoon season will increase reservoir levels to a maximum at the time of their arrival in autumn. The decrease in rainfall during winter months along with increased temperatures will increase demand for irrigation water releases, resulting in more rapid drawdown. The expected increase in temperatures and decrease in rainfall during winter months will shift the bioclimate zones of Pong Dam lake from Hot and Mesic towards Hot and Arid, which may change the migration patterns of these birds. Due to the expected increase in high wind events in the autumn and winter seasons, the winds and waves forming on Pong Dam lake may lead to disturbance of roosting birds and erosion of the shores where they congregate.

SENSITIVITY

These migratory birds are highly sensitive to the projected climate change trends, i.e., rising temperatures and increased flooding. Due to the increase in temperature during the hot season, shallow water habitats around the lake will warm up, which may affect the growth and populations of the aquatic vegetation and phytoplankton, which may further alter the availability of food for the dabbling ducks such as the Northern Pintail. Rising temperatures will increase evapotranspiration from riparian and terrestrial vegetation and the cultivation of winter crops, which will influence the availability of food for the Bar-headed Goose. Due to the expected increased flooding, increased erosion will bring more sediments into the lake and tend to shift the shallow zones towards the deeper parts of the lake, reducing the current mudflats zones, where the birds roost.

IMPACTS

All the climate change trends except flash flooding and more intense wind events will have strong impacts on these migratory birds. The attractiveness of Pong Dam lake as a staging post may change with a reduction in the numbers of Bar-headed Geese and Northern Pintail visiting Pong Dam lake. Conversely, increases in temperature at more southerly destinations may contribute to greater numbers of these birds remaining at Pong Dam lake throughout the winter. The following potential impacts on the habitat of the Bar-headed Geese and Northern Pintails are identified:

- Increased sedimentation in the reservoir due to augmented erosion will smother the aquatic habitat and shift mudflat zones.
- Downstream flooding due to frequent water releases from the reservoir can affect the downstream wetland habitats of these birds.
- Reduced onward migration of these birds due to increased winter temperatures further south, could give rise to higher numbers remaining overwinter at Pong Dam lake, thereby putting pressure on the availability of feed.
- Low water levels in the lake and low soil moisture affect winter crops and can affect the food supply available for migratory birds. Habitat changes may affect food availability during their residency.
- Disturbance of migratory birds by winds and waves, especially on the north-eastern shore in the afternoons may cause shifts of the birds to more sheltered bays, which may be less secure from predators and hunters.

ADAPTIVE CAPACITY

Part of the adaptive capacity of migratory birds is their ability to find the most suitable staging posts and destinations for their southward migration in October and northward migration in March. They will move around in search of the most attractive locations that provide roosting security and available food supplies to provide energy for onward migratory flights. The steady or increasing numbers of Bar-headed Geese and Northern Pintail visiting Pong Dam lake each year indicates that it continues to be attractive, perhaps more so than other areas on the flyway.

These migratory birds have a ‘medium’ adaptive capacity towards increase/decrease in rainfall during monsoon/winter season and floods/droughts but show ‘low’ adaptive capacity towards rising temperatures in the winter season. The use of the regulating structures in Pong Dam Lake to manage the flows and water levels in the lake provides a ‘medium’ capacity for the bird habitats to adapt to changes in rainfall and flooding events. If drought occurs in the winter months, then the migratory birds will have little capacity to cope with reducing the availability of food sources, and so may move away from the Pong Dam Lake.

VULNERABILITY

Bar-Headed Geese and Northern Pintail have a ‘high’ to ‘very high’ vulnerability to the increase in temperature during winter. To the extent that increased rainfall and floods during monsoon will affect the habitat and availability of food, these birds may be vulnerable to shortages during the winter period when they stay at the Pong Dam Lake. Similarly, the decrease in rainfall and drought during the winter period may affect food availability to which the birds are ‘high’ vulnerability.

4.7 Golden Mahseer

Asset description: Golden mahseer (*Tor putitora* Hamilton), one of the largest freshwater fish of the Indian sub-continent, mainly inhabits rivers in the foothills of the Himalayas, including the Beas river and Pong Dam Lake (Bhatt &Pandit, 2016). Generally, Mahseer populations have decreased by around 50% in the last two decades and has been classified under IUCN Red List criteria as Endangered (IUCN Red List), though the distribution of the species and their adaptability to varied habitats and food sources are potential arguments against its endangered status. In Pong Dam Lake, the catches of Mahseer in the reservoir has been remarkably consistency during the past 14 years with landings fluctuating between 25 – 50 tonnes per year (ICAR, 2021). It is widely known due to its large size, attractive golden colour, and food and sporting values. It takes periodic upstream migration during the pre-monsoon and monsoon from higher-order streams in the foothills to lower-order streams for spawning. In Indian waters, the fish can grow to the length and weight of up to 275 cm and 54 kg, respectively (Everard & Kataria, 2011; Nautiyal et al., 2008). The head length of the fish exceeds that of the body depth (Hora, 1939; Bhatt et al., 1998a). Large head, body and scales are important morphological characteristic features.

EXPOSURE

Various stresses and pressures have contributed to the ‘downward’ trend in the Mahseer population in the Beas river and Pong Dam, including habitat alteration by the creation of dams and illegal sand/boulder mining as well as poaching and indiscriminate fishing, as well as competition from other fish species. Fishing for Mahseer in the reservoir shows high variability according to the reservoir level and the declining water quality. The exposure to climate change threats will exacerbate these two conditions especially the increased rainfall in the monsoon period, the decreased rainfall and increased temperature in the dry season and demand for irrigation water causing rapid fall in reservoir level. Increased temperature in the reservoir water at lower water levels may reduce the dissolved oxygen and water quality. The water quality results appear to show a declining level of dissolved oxygen in recent years, although not below water quality standards for aquatic health.

SENSITIVITY

These species are ‘highly’ sensitive to change in climate as it affects the quality of water. The increase in water temperature and reduced dissolved oxygen level may be shifted beyond their ‘comfort zone’. The seasonal migrations upstream to spawn in the upper reaches of the incoming rivers are usually triggered by flushes or rainfall in the catchment at the beginning of the monsoon. If the early rains are delayed or inadequate, spawning may be impaired, with implications for the Mahseer

IMPACTS

Studies have suggested that changes in water quality can have a significant impact on the health of these fishes. Migration is closely related to Mahseer’s life cycle and the fish completes the early phase of its life cycle in the upper reaches of smaller streams and rivers. This makes the fry and fingerlings 'vulnerable' to risks and dangers from predators and exploitation by humans (Ogle, 2002) and being hampered by river regulation. High mortality in Golden Mahseer has been reported while undertaking upstream and downstream migration (Shrestha, 1997). Low fecundity in the species results in its declining numbers (William et al., 2005). This trait partially contributes to its vulnerability to decline. Delays in the breeding period may impair breeding success resulting in further reductions in the numbers of Golden Mahseer.

ADAPTIVE CAPACITY

Control of the water level and maintaining the DO concentration in the reservoir can significantly reduce the impact of climate variability and changes in water quality (Franklin, 2014). Controlled fishing during years of significant climate variability and regulations on fishing during periods of low flow can help sustain the number of fishes in the reservoir.

VULNERABILITY

These species are 'moderately' vulnerable as they are relatively resilient against climatic variations and are available in abundance in the Pong reservoir. The relatively 'high' adaptive capacity of this species with little variation in reservoir level reduces its vulnerability.

4.8 Fisheries

Asset description: Pong Dam lake has a huge potential for fisheries resources with an average open water area of 15,000 ha. Pong Dam lake fisheries provide nutritional and livelihood support to many poor fishermen who are fully dependent on Pong Dam lake resources. A total of 3,991 fishermen are registered with the Fishermen Co-operative Societies (ICAR, 2021). The decadal trend analysis of fish diversity indicated a 'decreasing' trend from 34 species in 1990-95, 28 species in 2014 and 20 species during 2020 (ICAR, 2021). The most abundant fishes among the small indigenous fishes were *Salmostoma phulo,* Elongated Glass Perchlet *(Chanda nama)* and *Osteobrama cotio (*ICAR, 2021).

EXPOSURE

The projected increase in rainfall during monsoon, when a majority of fishes breed, can alter the required flow and turbidity of the water essential for breeding, resulting in a decline in fish spawn availability (Vass et al., 2009). With an expected decrease in rainfall during winter (January-February), fisheries might be exposed to rapid rates of falling water levels, with fish production dependent on water level and inundated areas. The expected increases in maximum and average temperatures will shift bioclimate zones of Pong Dam Lake from Hot and Mesic, towards Hot and Arid. This would impact fisheries, as the temperature is particularly important for the maturation and breeding of fish. The increase in frequency and magnitude of flooding during the monsoon season will affect fish reproduction. Predictable annual flooding ensures reproductive success for fishes (McClanahan et al., 1996), whereas unprecedented flooding can lead to a decline in the fish yield as was seen after the 1988 flood at Pong Dam lake (GOI, n.d.). With an increase in high wind events, wind speed can either negatively or positively affect the quality of the fishing and the safety of fishing boats.

SENSITIVITY

Pong Dam lake fisheries are expected to be highly sensitive to the projected climate change trends, especially the increase in temperature and consecutive drought days. As temperatures are projected to rise during the hot season and monsoon (June-September), the growth and yield of many fishes found in the Pong Dam lake would be sensitive. The projected rise in consecutive drought days during breeding months can lead to a decline in fish spawn availability (Vass et al., 2009). During the monsoon with increased soil erosion and sediment from the catchment, the fisheries may be sensitive to the increased turbidity of the water and concentration of suspended particles

IMPACTS

All considered climate change trends except a decrease in rainfall during winter show a high impact on fisheries assets as follows:

- Fish production is dependent on water level and area, so may decrease more rapidly as water levels fluctuate and are drawn down

- Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water.
- Increased reservoir filling and area may enhance fish productivity and hence resident fish-eating birds e.g. cormorants.
- Fish culture facilities may be impacted by damage from flash floods, and raised temperatures may cause cultured fish mortality and disease
- The impact on the culture system will reflect any reduction in water quality and limitations in the culturable water area and volume. As a result, there will be a decrease in fish production
- High winds and large waves will make boating more challenging for fishing activities

There are some positive and negative impacts of climate change on fisheries. However, negative impacts override the positive impacts and it is projected that there might be a decline in overall fish yield in future under climate change.

ADAPTIVE CAPACITY

The fisheries asset has a 'moderate' adaptive capacity to floods, as reservoir water levels are regulated and can be managed by the hydel in case of flooding. Fisheries have a 'medium' to 'low' adaptive capacity for projected increasing consecutive drought days, the decrease of rainfall during winter and the increase of temperature during the hot season/monsoon. This is because there is no possibility of natural adaptation to this range of high temperatures. The adaptive capacity of the fishing livelihoods towards the projected increase in high wind events and wind speed in autumn and winter is 'very low', as only limited effectiveness can be achieved through natural or management measures except for providing safer fishing and boating craft.

VULNERABILITY

Fisheries are 'highly' vulnerable to the increase in temperature during the hot season due to a 'high' impact level and a 'low' adaptive capacity. It has a 'high' vulnerability to floods and droughts as well, due to 'high/very high' impact levels and 'high/medium' adaptive capacity. Fisheries show very high vulnerability towards more intense wind events due to high impacts and a very low adaptive capacity.

5 ADAPTATION PLANNING

This chapter presents options for adaptation to climate change for the Pong Dam lake. The potential impacts of climate change on the wetland's components are interlinked and particularly contingent on the impacts and vulnerability of the system's hydrology, habitats, and biodiversity. Thus, the approach to promoting effective wetland adaptation must address the vulnerabilities of these natural components. The Adaptation Planning Matrix for each of the target assets developed using the CAM method is attached as complementary material to this report (a list of files shown in Annex 4).

5.1 Catchment

Pong Dam has a large catchment area of approximately 12,000 km^2 leading into the 250 km^2 reservoir with 156 km^2 of the inundated wetland area. Major challenges the catchment is expected to face due to climate warming include flooding and landslides events associated with extreme precipitation events. Change in the discharge pattern of the rivers is associated with melting and receding glaciers and GLOFs. Soil erosion in the catchment is also expected to increase because of the increased intensity of rainfall during the monsoon. In addition, changes in local characteristics are expected such as a change in soil texture, reduction in flora and fauna especially related to endangered species and medicinal plants.

5.1.1 Increase of Monsoon rainfall in quantity and intensity

The increase in rainfall during the monsoon season is likely to come with increased frequency and intensity of rainstorm events falling on an already degraded catchment. This will lead to increased risk of landslides on the steep and less stable slopes in the upper catchment and increased soil erosion where the forest cover has been removed and in the traditional farming areas on the lower slopes. While nothing can be done to moderate the rainfall patterns, adaptation measures should focus on reducing run-off and increasing infiltration into ground water with good integrated catchment management practices. In addition, because soil erosion will lead to increased sedimentation in the reservoir, shortening the life of its active storage and changing the substrate in areas frequented by the migratory birds, active adaptation measures should be put in place to a) conserve the soils and b) prevent sediment transport within the streams and rivers flowing into the reservoir.

ADAPTATION MEASURES

The needed adaptation measures include:

A survey of land use and land cover in the catchment to identify deforested and degraded areas at risk of increased run-off and soil erosion. These are the areas most at risk from climate changes in rainfall, and where watershed management plans should be focused.

Development of forest conservation plans and watershed management plans Soil conservation measures can be carried out by planting trees and a diversity of vegetation in the areas susceptible to erosion and construction of check dams and river bank stabilisation in the rivers and streams that feed into the reservoir. However, the DFO notes that only a limited area is available for plantation and increasing vegetation cover.

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 nature based adaptation measure will grow with time as trees mature, so this measure will take time to establish and is labour intensive. An important goal is to ensure net biodiversity gain through the adaptation measures.

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

The activity would be conducted by the Forest Department as part of their regular mandate and program. 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 program.

Development and extension of minimum cultivation practices for agricultural areas to reduce soil erosion. Changing traditional agricultural practices inevitably takes time – the new soil conservation methods need to be accepted by local farmers. Yet, they can become an extremely effective set of tools for increasing infiltration of rainfall, maintaining soil fertility and reducing erosion. The research and development of appropriate minimum cultivation techniques and extension packages would have to be carried out by the Department of Agriculture.

Obstructing the natural flow of water entering the Pong reservoir for silt control and increased ground water recharge can be achieved through a range of nature based and hybrid measures including bunding, diversion drains, contour trenches, stone walls, retaining walls and check dams as silt traps. 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 a 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 program involving DOF and BBMB. The main objective of IWMP is to restore the ecological balance in target areas by harnessing, conserving and rehabilitating degraded natural resources. It involves community mobilization and social organization.

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 catchment area runoff. 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 coordination with 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 stabilization and control of sediment runoff particularly in mountainous slopes. Bioengineering techniques can be used to enhance slope stability. Brush-mattress structures, wattle (wicker) fences, long brush barriers, and fascines are some of the slope stabilizations bioengineering measures which can be undertaken. These are low-cost measures but labour intensive with costs covered under MANREGA so that it has less impact on the Forest Department's annual budget.

Drainage lines which 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 which 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 allocation, the overall principle of using nature based measures in the Pong Dam adaptation plan should be followed. Even when hard structures are essential, a hybrid integrated green and grey approach should be taken. This activity would 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 in steep slopes. In 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 so initial costs are quite high but these activities can be planned for the long term with labour costs be covered under MANREGA.

5.1.2 Increase of temperature during the hot season/Monsoon (June-September) and during the cold season (October-May)

The changes in temperature during both hot and cold seasons will have impacts upon the rate and timing of snow melt in the upper catchments and will contribute to the progressive retreat of the glaciers in the headwaters of the Beas river. This will change the hydrological regime and filling patterns of the Pong Dam lake, and in the long term may reduce the overall quantity of water available. The retreat of the glaciers may allow the development of new glacial lakes or threaten existing glacial lakes. The risks of Glacial Lake Outburst Floods (GLOFs) are likely to increase in the future.

In the lower catchment, the increasing temperatures, coupled with decreased rainfall during the hot and pre-monsoon periods may stress some of the more sensitive plant species in the catchment, such that endangered plants and species with herbal uses may decline, threatening both biodiversity and local medicinal values.

ADAPTATION MEASURES

While nothing can be done to stabilise the hydrological regime, the adaptation measures will include:

Monitoring the inflows and outflows of the Pong Dam lake and identifying long-term changes so that the filling and draw down rating curves of the reservoir can be adapted. The risks of changing these operational patterns are that this may change the ecology of the reservoir, especially the habitats favoured by the migratory birds. The operation of the Pong Dam Hydel plant is the responsibility of the BBMB, but any proposed changes in filling and draw down of the reservoir should be considered in consultation with the Himachal Pradesh Wetland Authority.

Regular survey of the glacial lakes most at risk of GLOFs and preventative measures taken to reduce these risks. Surveys of the glacial lakes should be carried out at least every 5 years. This should follow up on the 2004 surveys carried out by International Centre for Integrated Mountain Development (ICIMOD) and Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University (CSKHPAU) (Bhagat et al., 2004). Various precautionary measures may be considered, including cuts and tunnels to drawdown the lakes most at risk, and the construction of artificial dams to strengthen the natural moraine dams.

Within the catchment, vegetation surveys of Endangered plants and species with herbal value should be carried out to identify the most vulnerable species and their locations, so that these can be monitored in the future to assess changes in populations and possible decline. This should be carried out as part of the Pong Dam research programme in collaboration with the Forest Department.

5.1.3 Flood/Flash flood

In addition to GLOFs, the catchment is prone to flash floods in the event of high intensity rainfall events and landslides. In the past, there have been some very damaging floods that have passed down the Beas river, through the reservoir and downstream of the Pong dam lake.

ADAPTATION MEASURES

Plans should be developed for management of flash flood events within the Beas river catchment. Management measures may include flood risk forecasting systems with the regulation of water levels in the reservoir to provide volume for forecasted flooding events both in Pong Dam and in the upstream Pandoh Dam; identification of sacrifice land for temporary diversion of flood waters and construction of flood retention dams. Flood and emergency preparedness should be put in place with relevant authorities. The development of the flood management plan should be the responsibility of the BBMB.

Landslides are often caused by storm events and these can cause or exacerbate flash floods. Management and conservation measures for specific landslide-prone areas in the catchment should be considered as part of the Catchment Management Plan developed with the Forest Department and BBMB. Emergency and rescue teams should be trained to cope with these extreme events.

5.2 Pong Dam Hydel

The water stored in the Pong Dam lake is primarily used for meeting irrigation water demands for which a total of 7,913 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. Although there is projected to be an increase in rainfall during the monsoon, which will fill the reservoir more quickly, the hydel project will be vulnerable to the decrease in rainfall during winter, coupled with increased temperatures downstream, which will increase the demand for irrigation water.

The Pong Dam hydel plant is the key water regulating structure in the Beas river basin. The way in which it will be operated as climate changes become more evident will be important for the future health of the Ramsar wetland ecosystem, especially for the migratory and resident bird species and for the fish, fisheries and tourism, and for the downstream wetlands.

5.2.1 Increased risks of intensive rainfall and flash flooding during the monsoon

ADAPTATION MEASURES

The BBMB should **monitor the changing hydrological patterns of inflow of water from the catchment and demand for irrigation and domestic water supply downstream of the dam,** and adapt the requirements for filling and drawdown of the reservoir throughout the year. In doing so the BBMB should consult with Himachal Pradesh Wetland Authority and Forest Department on changing patterns of filling and drawdown of the reservoir and potential implications for wetland ecosystem health.

The BBMB should **strengthen flood preparedness strategies for the Pong Dam Hydel,** including exploring, redesign, improve or remove upstream physical structures, which are barriers to flows, migratory fish and floodwaters. Flood water storage volumes within the reservoir should be managed by releasing water downstream in anticipation of forecasted high rainstorm events.

The BBMB already maintains the Pong Dam and its hydraulic structures and will need to consider the damages of floods and increased temperatures on these structures and equipment as part of their regular maintenance, to assure the safety of these structures.

5.2.2 Decreased rainfall in winter and pre-monsoon and increased temperatures

During future dry, winter and hot seasons, the lake level will be drawn down more quickly and there will be less water available for hydropower generation and irrigation, and downstream environmental flows are likely to be reduced. There will be an increase in evapotranspiration in the lake with less water available for irrigation and power generation. Arable winter crops grown around the lake may be less productive because of the quicker drawdown, with fewer crop residues available as food for migratory birds.

ADAPTATION MEASURES

- In operating the Pong Dam Hydel, the BBMB should try to maintain the hydrological balance of the reservoir and patterns of filling and drawdown as well as the environmental flows downstream. The current patterns are beneficial for migratory birds and should be maintained as far as possible.
- The Wetland Authority and the Forest Department should study the hydro-ecological requirements of the Ramsar site in the light of potential changes in the hydrological balance and management of the reservoir and monitored the impacts of these changes in the long term, so that they are prepared for consultations with the BBMB.
- The efficiency and effectiveness of the irrigation system downstream should be reviewed to minimise wastage of water, and climate and drought resilient cropping systems should be developed for application in the command areas of Pong Dam. This should be done by the Irrigation Departments and Agriculture Departments of the States served within the Command Area.
- Restoration of important degraded habitats around the reservoir and downstream should be conducted, such as regeneration of wetland areas downstream, re-vegetation of riparian forests and tree-planting.
- Increase vegetation cover in surrounding areas of the reservoir is needed to reduce evaporation and erosion.
- Conduct a program of research and development on climate-resilient crops, both for upstream irrigated areas and around the reservoir.

5.3 Pong Reservoir

The reservoir habitats consist of open deep water, shallow water in the drawdown, dry sandbanks with little or no vegetation, waterside vegetation and swamps below the out-fall from the dam. This reservoir covers 24, 529 ha and the wetland portion is ~15,662 ha. The maximum water level under BBMP is 1,410 feet above msl, and in case of maximum submergence it affects migratory bird feeding sites due to unavailability of grass and crops.

The reservoir length is 42 km long with a maximum width of 19 km, the mean depth of the reservoir is 35.7 m. The surface water temperature of the lake varies between 22.2°C and 25.1°C. Monsoon rainfall between July and September along with snowmelt is the major source of water supply.

5.3.1 Increase of rainfall during Monsoon

The major issues that the reservoir is expected to face due to the increase of rainfall during the monsoon are the increased sedimentation from soil erosion in the catchment coupled with loss of active storage capacity within the reservoir. The loss of active storage reduces the potential for use of the water for irrigation downstream and the associated power generation.

ADAPTATION MEASURES

The adaptation measures include the conservation of forest in the catchment to reduce erosion and sedimentation and the construction of sediment traps in the rivers and streams before the confluence with the reservoir. This should be part of forest conservation and watershed management plans to be undertaken by the Forest Department in conjunction BBMB. Concepts for these measures have been provided in Section 5.1 The DFO suggested that trenching as has been done in the Sansarpur Forest Reserve downstream of Pong Dam lake may also be piloted in the Pong Dam catchment.

If sedimentation in the reservoir becomes too much of a problem, mechanical methods of sediment removal including dredging and pumping, but these tend to be costly and can be damaging to the water quality and key habitats within the reservoir. The disposal of the dredging spoils can also be a problem. Sediment removal from the reservoir would be the responsibility of BBMB, in consultation with the HP Wetland Authority and Forest Department.

5.3.2 Decrease of rainfall during Winter and pre-monsoon season

The main impact of the decrease of rainfall in other seasons is likely to be the increase in demand for irrigation water downstream of the dam, which will lead to a changing balance of supply and demand in the reservoir discharge. This may result in a more rapid fall in the water levels in the reservoir, which would make the exposure of the drawdown more extreme, thereby reducing its suitability for vegetation and productivity. This would exacerbate the “bath-tub” effect with wide expanses of unvegetated bank around the reservoir.

ADAPTATION MEASURES

The main adaptation measure to be considered for addressing this impact is the adjustment of rates of drawdown through the modelling of irrigation water release plans. The regime would be dependent on the likely demands of the downstream states under different climate change conditions, which would aim to maintain acceptable drawdown rates. Such plans would be developed by the BBMB in consultation with the HP Wetland Authority, and Forest Department to ensure that the rates of drawdown are kept within levels which do not damage the reservoir ecology.

An alternative measure that would retain some productive areas within the drawdown is to create perched wetland areas that are permanently covered with water. These can be constructed by an earth bund around an inlet or small stream flowing into the reservoir, which retains the water while the main body of the reservoir is being drawn down. When the water level rises again, the earth bund is refilled and reconnected with the rest of the reservoir.

5.3.3 Increase of temperature during the hot season and Monsoon

The principal risks to the reservoir arising from increasing temperature during the hot season and monsoon are the increased evaporation losses from the surface of the water, which will need to be considered when developing the irrigation water release plans. More importantly for the quality of the reservoir, increases in surface water temperatures could give rise to stratification of the water column with low DO in the deeper parts of the reservoir. Under certain weather conditions, e.g., with the strong winds in the early winter months, this stratification may breakdown, bringing poor water quality water to the surface, with the possibility of fish mortality both within the reservoir and downstream. The risks of stratification and growth in phytoplankton is likely to be exacerbated by nutrients being washed in with the sediments and run-off from urbanization and agricultural fields.

ADAPTATION MEASURES

Adaptation measures to reduce the impacts of increasing temperatures range from the planting of trees and tall bushes on the reservoir banks and shading certain sections of the reservoir to keep temperatures lower and reduce evaporation losses. On a larger scale, the feasibility of constructing floating solar panels to generate additional electricity and to shade the water from the increased temperatures. The latter would require considerable investment and would be implemented by BBMB.

To reduce the risks of poor water quality arising from stratification and phytoplankton blooms, several measures may be considered. If stratification and turn-over develops as a regular phenomenon at certain times of year, mechanical aerators or circulating pumps can be installed to break up the layers of water and make sure that the water column becomes well mixed. This would also require considerable investment and would be implemented by BBMB.

The inflow of nutrients of the catchment from the washed-in sediment and run-off from urban areas and agricultural fields, may need to be controlled to reduce the risks of eutrophication. The nutrients carried in from the sediments may be controlled by various methods described earlier to reduce the quantities of sediment reaching the reservoir. The run-off from urban areas should receive pollution control treatment and enforcement, which would be implemented by the district authorities and municipalities concerned. The nutrients in the run-off from agricultural areas could be managed by extension and promotion of organic farming or minimum chemical methods in the agricultural areas within the main catchment of the reservoir. This would be managed through the Department of Agriculture.

These are all long-term and labour intensive measures that would have to be planned in response to observed changing conditions in the reservoir, such as water temperatures and DO profiles and phytoplankton or chlorophyll content. The main short-term adaptation measure will be the monitoring of conditions in the reservoir and trends in water quality.

5.3.4 Flood/Flash flood

Extreme events such as floods and flashfloods, including GLOFs, can be extremely damaging to the reservoir and downstream areas, especially if the water levels are already very high and there is little storm storage capacity in the reservoir.

ADAPTATION MEASURES

The flood adaptation measures in the catchment have already been described in section 5.1.3., including the regular survey of the GLOF risks from glacial lakes and the development of flood modelling and routing studies through the Pandoh and Pong dams. The most immediate adaptation measure is the development of flood warning and forecasting systems to prepare the reservoir to receive and delay large flood flows. In anticipation of intense rainstorm events, the water level in the reservoir should be lowered through the release of water downstream to create the necessary storage capacity in the reservoir. Bhakra Beas Management Board (BBMB) has set up an Earth Receiving Station (ERS) at Chandigarh for inflow flood forecasting (i.e. short term 3 days and medium term 7 to 10 days) for optimum utilization of Bhakra and Pong Reservoirs and Canal Network[12].

5.4 Migratory bird habitats

The most important habitats for migratory birds are found along the north-eastern shore of the reservoir e.g., at Nagrota Surian. Pong Dam lake lies on the flyway of migratory birds and provides secure habitats for roosting and resting after migration and a natural habitat with flat shallow areas and mudflats that retain aquatic plants and rhizomes with access to crops and crop residues for birds to feed. The adaptation measures are designed to maintain or enhance the attractiveness of the habitats and food for migratory birds around the Pong dam lake.

If the climate conditions change to make the Pong Dam lake area more attractive so that more birds do not migrate further south where temperature increases may be too intense, the capacity of the Pong Dam lake to sustain the larger populations may come under pressure with less food sources available.

5.4.1 Increase of rainfall during Monsoon (June-September)

The increase in rainfall during the monsoon period before the migratory birds arrive could have adverse impacts on the roosting and feeding habitats used by the migratory birds around the reservoir. Increased sedimentation or flushing by floodwaters could substantially change the mud and sandbanks where the birds rest and the shallow waters where they feed. These habitats could shift and reduce in area, and so the carrying capacity of these habitats for migratory birds is lowered.

ADAPTATION MEASURES

The preferred conditions for the roosting and feeding areas of the migratory birds should be studied so that prior to the arrival of the migratory birds in September/October, the reservoir water levels can be appropriately regulated to maintain the habitats in good condition.

Additional habitat areas and diversity can be developed with perched wetlands, mounds and depressions at the edges of the reservoir that provide both roosting and permanent shallow water areas for feeding. These areas would not be subject to rapid drawdown of the water levels or flushing out of the productive substrate.

Bunds can be constructed to reduce the erosion on the north-eastern shoreline; however, there should be no bunding at the confluence of the main *khads* with the reservoir since the connectivity between the *khads* and the main reservoir is important for birds and for migratory fish such as the Golden Mahseer.

[12]https://bbmb.gov.in/achievements-of-bbmb.htm

Silt traps and level measurement devices can be installed to understand the response of various extreme events on the areal extent of these roosting and feeding areas. These adaptation measures should be undertaken by the Wetland Authority and the Forest Department in consultation with BBMB to identify the locations where these habitat modifications can be put in place.

5.4.2 Decrease of rainfall during winter (January–February)

The effect of decreased rainfall during the winter periods when the migratory birds are present may be to reduce the vegetation growth and winter crops in the areas surrounding the reservoir so that less food is available for birds feeding on terrestrial plants and crop residues. With less food available, the birds will recover more slowly after their long flights over the Himalaya, and will be less prepared for onward migration.

ADAPTATION MEASURES

To ensure that adequate food sources are maintained at the wetland for the migratory bird population, the following adaptation measures can be developed:

Habitat improvement can be carried out in areas that become too shallow to serve as feeding grounds for aquatic birds that feed on aquatic plants and invertebrates, e.g., removal of new sediments from the original substrate and planting of appropriate aquatic plants, including in the perched wetlands. More resilient plant species can be identified that will provide adequate habitats and feed for the migratory birds.

To overcome the issues of limited availability of food supplies for migratory birds, special cropping systems can be developed in the recession agriculture area around the reservoir. Dedicated crops for the migratory birds could be grown in some areas, and an agriculture adaptation plan can be developed to change the cropping patterns during low rainfall years. In addition, the Wetland Authority could consider establishing a fund for insurance of winter crops damaged or lost by feeding migratory birds, so as to reduce the human–bird conflict and hunting pressure.

5.4.3 High winds and waves

In autumn, the frequency and intensity of winds blowing across the reservoir towards the preferred roosting grounds are likely to increase. The birds may be regularly disturbed by these strong winds so that they move to less secure sites around the reservoir, where they may be exposed to predators and hunters.

ADAPTATION MEASURES

To overcome such security issues, a study on the preferred and alternative roosting areas around the reservoir should be carried out so that additional protection measures may be provided, e.g., declaration of sanctuary areas.

5.5 Bar-headed Geese and Northern Pintails

The migratory Bar-headed Geese (> 45% of the world's population) and Northern Pintails are seen in the large congregations in this wetland in winter. Bar-headed Geese are herbivores and feed mainly on the grasses that surround the lakes where they nest. They also eat corn, barley, rice, wheat and occasionally molluscs, insects and crustaceans. The Northern Pintail feeds by dabbling and upending in shallow water for plant matter mostly in the evening/night. The Bar-headed Geese breeds in high-altitude wetlands in Central Asia at 4000–5000 m, while the Northern Pintail breeds throughout the northern Palearctic.

The impact of climate change on the breeding success of migratory birds has not been assessed in this study, which focuses on Pong Dam lake. Interviews with stakeholders suggested that breeding grounds of migratory birds should be declared as protected areas. The only breeding site for the Bar-headed Geese within India is the Tsomoriri Ramsar site in Ladakh.

5.5.1 Increase of rainfall during monsoon and decrease of rainfall during winter

The vulnerabilities of the Bar-headed Goose and Northern Pintail to increases in rainfall during the monsoon and declines in rainfall during the winter are 'very high' or 'high'. The impacts are related to alteration in the roosting and feeding habitats and changing the availability of food sources. Thus, increases in rainfall in the monsoon will tend to increase soil erosion in the catchment, leading to sedimentation in the shallow areas of the reservoir, smothering the aquatic habitats, shifting the mudflats and reducing the areas available for the dabbling ducks to feed in. The reduction in rainfall in the winter may reduce the productivity of the winter crops and vegetation for the geese and other terrestrial-feeding birds.

ADAPTATION MEASURES

The adaptation measures proposed will require detailed surveys and research.

- Carry out a detailed habitat study, including mudflat zones, clear water, shoreline and adjacent croplands, and of migratory birds' feeding patterns, e.g., which are the preferred crops, grass and other vegetation for Bar-headed Geese and Northern Pintail.
- Develop guidelines on the optimum filling and drawdown rates of the reservoir for maintaining the extent and quality of the migratory bird habitats. This should be done in consultation with the BBMB, HP Wetland Authority and Forest Department.
- Monitor the annual changes in hydrology, vegetation cover and sedimentation, in the areas frequented by the migratory birds to assess the progressive impacts on mudflats, sand bars, and water quality. This should include research on the zooplankton and aquatic plants which are essential feed for dabbling ducks such as Northern Pintail.
- Within the reservoir area, create additional habitat diversity with the addition of perched wetlands, mounds and depressions within drawdown areas and in the wetlands downstream of the reservoir. These constructions will use dredged sediment from the drawdown areas, which will also help maintain the active storage volume in the reservoir. This should be the responsibility of the HP Wetland Authority and the Forest Department, which should be in consultation with BBMB.
- The area 1410 feet above Pong Dam lake is not under the jurisdiction of BBMB, and it provides a critical habitat used by migratory birds. Some nearby areas, including riparian and flooded forests and associated wetlands, should be designated as protected areas that provide additional security for the feeding and roosting of these species. This will require spatial investigation, remote sensing and ground-truthing to be carried out by the Wetland Authority and Department of Forests to identify those areas more frequently used for feeding and roosting.
- To ensure that there are sufficient food resources available for terrestrial feeding birds such as the Bar-headed goose, dedicated cultivation of vegetation and crops in the drawdown of the reservoir may be considered. This should be carried out by the Forest Department, by contracting local farmers to plant these crops for the geese.

The vulnerability of the Bar-headed Goose and Northern Pintail to the rise in temperature during both the hot season and winter is high. Increased winter temperatures may lead to changes in numbers of birds visiting Pong Dam lake. This may be a decrease in numbers because more birds prefer to overwinter elsewhere, or there may be an increase in birds remaining at Pong Dam in winter because the temperatures become too high in sites further south.

Although the migratory birds are not directly affected by increased temperatures during the hot season and the monsoon, they may be indirectly affected by changes in the populations of aquatic species on which the ducks depend for food in winter. During summer, the water temperature is likely to increase, possibly beyond threshold limits for some aquatic species. And the increases in temperature during winter may also change the populations and availability of aquatic plants and macroinvertebrates. These changes cannot be predicted without further research and monitoring.

ADAPTATION MEASURES

It is necessary to maintain regular migratory bird counts each year, and correlate migratory bird visits with other known winter migration destinations. Try to correlate changing migration patterns with changing climatic and habitat conditions in both Pong Dam lake and other overwintering destinations. This will help understand the migration patterns and the responses of the birds to climate changes.

Regular observations of local movements of migratory birds around the Pong Dam lake Ramsar site and adjacent areas are needed to assess the effects of habitat degradation and human disturbance upon their roosting and feeding patterns. GPS-based monitoring of local bird movements could be used for this survey.

This monitoring should be carried out annually by the Forest Department with counts and movement observations during the overwintering season.

5.5.3 Extreme events – Floods and wind

The Bar-headed Geese and Northern Pintails are highly vulnerable to the increase in frequency and intensity of floods and to the increase in high winds and waves blowing across the reservoir in extreme events. The major impacts of flash flooding are increased sedimentation or erosion of the mudflat zones at the deltas of the *khads* where they meet the reservoir so that the main roosting areas of the geese and ducks are shifted. High winds and waves can also cause erosion of the north-eastern shorelines of the reservoir and temporarily disturb the migratory birds, causing them to shift to other locations in more sheltered bays that may not be as secure from predators or hunting.

ADAPTATION MEASURES

The adaptation measures that have been described to manage floods in the catchment should be adopted for protecting the sensitive habitats used by the migratory bird species (see sections 5.1.3 and 5.2.1). The creation of additional habitat diversity (perched wetlands, mounds, depressions and bunds within drawdown areas) will also help provide protection to the migratory bird habitat against extreme flooding and wind and wave erosion along the North-Eastern shoreline. When constructing flood management infrastructure within the catchment, attention should be paid to maintaining normal free flows and connectivity for the movement of aquatic species, including birds and fish.

5.6 Golden Mahseer

The Golden Mahseer (*Tor putitora),* one of the largest freshwater fishes of the Indian sub-continent, is mainly found in rivers in the Himalayan foothills, including the Beas river and Pong Dam lake. It migrates up the feeder rivers and streams during the monsoon, when flows are high to spawn, returning to the reservoir during the winter. The Golden Mahseer population has decreased by around 50% in the last two decades.

5.6.1 Increased rainfall during the monsoon

The vulnerability of the Golden Mahseer to the increased rainfall during the monsoon is ‘high’. The increase in rainfall during the monsoon could be beneficial because the flows down the rivers and streams where the fish spawn will be increased so that their passage upstream is facilitated. However, the main negative impact will be on the spawning habitats – shallow gravel beds – which may be washed out by high flow events or smothered by excessive sediment from the increased soil erosion in the catchment.

ADAPTATION MEASURES

The main adaptation measures will be the improved catchment management actions to control soil erosion and sediment transport down the rivers and streams. These measures have been described in section 5.1.1 and include reforestation, soil conservation agricultural techniques and construction of check dams and sediment traps. However, barriers constructed within the rivers and streams should allow the passage of Mahseer both moving upstream to spawn and returning downstream to the reservoir. Additional fish habitats within the reservoir may be developed by the construction of permanent perched wetlands or depressions within the drawdown zone. These adaptation measures should be undertaken by the BBMB and Forest Department in consultation with the Fisheries Department and representatives of the fishers.

5.6.2 Increased temperature during the hot season and monsoon

The Golden Mahseer is a cool water fish, which is vulnerable to rises in water temperature especially during the hot season. During winter, although rises in temperature are expected, these will not be above the comfort threshold of the species. Yet, the surface water temperature during the hotter months may exceed the preferred temperatures of the Golden Mahseer, which will impact its growth and survival, particularly if the increase in temperature is associated with decreasing DO content in the water below a typical water quality threshold of 5 mg/l, and development of stratification of the water layers. If conditions develop within the reservoir where anaerobic water is brought to the surface, e.g., after a long hot season, fish mortality could occur.

Increasing water temperatures and flows may also be a trigger for spawning migrations up the rivers and streams. Spawning patterns may be disrupted if these conditions begin to occur earlier in the year.

ADAPTATION MEASURES

While little can be done about the projected increases in air temperature, measures can be taken to reduce the direct warming of the water surface through shelter belts of trees grown around the edges of the reservoir and growing floating aquatic plants, such as Water Lily, Small and Great duckweeds and Watermeal, may be encouraged in some parts of the reservoir, e.g., in the constructed perched wetlands and depressions. However, the large areas of open water in the bulk of the reservoir cannot be so protected. The construction of floating solar electricity plants can also shelter the water surface, but this may have other effects on the water quality, creating adverse conditions for the fish.

The development of stratification of the water layers with increased surface water temperatures will need to be monitored, especially during the hot season, into the monsoon. If anaerobic lower layers develop, it may be necessary to encourage early mixing of the layers and oxygenation techniques, through recirculating pumps, mechanical mixers and diffusers.

Research should be carried out on the triggers for Mahseer spawning migrations to assess the likely impacts of increased temperatures and flows upon spawning behaviour. All these suggested adaptation measures will require research, planning and consultation with the different stakeholders, with the lead taken by the Fisheries Department.

5.6.3 Extreme events – floods and droughts

As with all the fish species and production in the reservoir, the Golden Mahseer population is generally dependent on the water level. The higher the water level is maintained for longer, the greater the productivity and species richness. Extreme events can alter water levels significantly, with floods rapidly increasing the water levels to over the full supply level and droughts causing excessive and prolonged drawdown in the reservoir. While floods can obviously be beneficial in maintaining high water levels, they can also degrade the riverbed and substrates in the inflowing rivers and cause smothering of the substrate with fresh sediment within the reservoir.

ADAPTATION MEASURES

When developing flood management measures such as construction of barriers or retention reservoirs within the catchment (see 5.1.3. and 5.3.4), care must be taken to avoid the main spawning grounds of the Mahseer and to provide fish passages up and down the rivers and streams where these barriers are built. This will require habitat surveys of the inflowing rivers to identify the preferred locations of the Mahseer spawning, and their migration routes as part of the data system for flood control and reservoir water level forecasting. Specific Mahseer Conservation Zones within the rivers and streams may be necessary to protect the main spawning grounds. This measure would be carried out by the Fisheries Department.

Within the reservoir, the smothering of habitats with excess sediments may require regular sediment removal using dredgers and mechanical diggers. However, this process needs to be done with care to avoid destroying the habitat completely and needs to be carried out regularly in smaller areas, allowing the fish habitats to recover, rather than occasionally in large dredging campaigns. In the drawdown areas, removal of sediment and creation of mounds, bunds and depressions would best be carried out when the areas are exposed, to minimise the impacts on the water quality and fish. Sediment removal should be carried out by BBMB, but in consultation with the Fisheries Department.

While it is going to be difficult to maintain water levels during droughts due to the demands for irrigation water downstream, the impacts of reducing water levels on the Mahseer and other fish need to be recognised. As the water level reduces, it becomes easier to catch the fish, with higher numbers being caught in nets, especially in locations where the fish congregate. Thresholds of the water level in the reservoir should be established when regulation of fishing activity is triggered, e.g., banning the use of certain gear, banning certain catch sizes and even complete bans of fishing until water levels start rising again. This measure should be carried out by the Fisheries Department.

5.7 Fisheries

With an open water area of 15,000 ha, Pong Dam lake has a huge fisheries potential. The fish production averages about 400 tons of fish per year, with annual variations linked to the water levels of the reservoir. It provides the main livelihood for about 2200 poor fishermen who are fully dependent on the reservoir. The reservoir is also a resource for angling and recreational fishing.

5.7.1 Changes in reservoir level due to increased rainfall in the monsoon and decreased rainfall during winter and the hot seasons

The productivity of the Pong Reservoir fisheries is dependent on the water level and extent and length of the inundation period. The length of time that the reservoir will be at full supply level and the rate at which drawdown occurs depends on the patterns of rainfall in the monsoon and the demand for the release of irrigation water to the downstream states during the winter and hot seasons. The water level is not regulated according to the fishery requirements, and so there is little adaptive capacity in the system for counteracting impacts of changes in rainfall on the fisheries.

ADAPTATION MEASURES

The impacts of reducing water levels on the Pong Dam fishery need to be recognised. As the water level reduces, it becomes easier to catch the fish, with higher numbers being caught in nets, especially in locations where the fish congregate. Thresholds of the water level in the reservoir should be established when regulation of fishing activity is triggered, e.g. banning the use of certain gear, catch size and even complete bans of fishing until water levels start rising again. A study to determine the optimum number and locations of fish nets and traps will be necessary if additional licensing and quotas or changes in the types and sizes of fishing gear are required. This should be carried out by the Fisheries Department in consultation with BBMB on water level regulation.

In addition, it may be necessary to establish Fish Conservation Zones (FCZ) within the reservoir, where no fishing is allowed at any time to provide refuges for the fish and to allow spawning and growing safe from fishing pressure. Reservoir FCZs should be based upon appropriate survey of the best refuge and spawning areas within the reservoir carried out by the Fisheries Department, and in consultation with fishermen. The survey should also assess changes in the hydrology and sedimentation of these locations, the water quality and the habitat conditions of the mudflats and sand bars. If the habitats in these zones become degraded, the revenue from fish catch auctions at the end of the wet season in each community could be used for their restoration.

Enforcement of the fisheries laws and regulations and local rules with active community participation will become more important, especially enforcing that there is no fishing during the spawning season. The number of fishermen is already regulated by licensing by Fisheries Department who should also be empowered to enforce these rules and regulations. Consultation on the design of fishing regulations and local fishing rules, raising awareness about these and establishing FCZs is important for achieving compliance with the rules and regulations.

5.7.2 Increase of temperature during the hot season and monsoon

The Pong Dam lake fisheries are ‘highly vulnerable’ to a rise in the temperature during the hot and monsoon seasons. The major direct impacts are the raised surface water temperatures which may result in decreased DO concentrations, possibly below the threshold levels of 5 mg/l, and may lead to stratification of the water column at certain times of year. When the lower layers of water with anaerobic (low DO levels) are mixed with surface layers, fish mortality can occur.

The increases in temperature throughout the year can increase the growth of the phytoplankton and the associated zooplankton. This may be beneficial in that there is more planktonic food for the fish, but if algal blooms occur, this can lower the water quality and cause fish mortality, especially if the blooms contain toxic cyanobacteria.

ADAPTATION MEASURES

The adaptation measures for the Golden Mahseer under section 5.6.2 are appropriate for reducing the impacts of increasing water temperature on fish populations and fisheries.

The development of stratification of the water layers with increased surface water temperatures will need to be monitored, especially during the hot season, into the monsoon. If anaerobic lower layers develop, it may be necessary to encourage early mixing of the layers and use oxygenation techniques, through recirculating pumps, mechanical mixers and diffusers.

The inflow of pollutants and nutrients into the reservoir through urban and industrial effluents and agricultural runoff, in combination with raised water temperatures, is likely to enhance algal growth, with more frequent blooms and potential toxicity problems. A survey on the locations and size of current pollution sources flowing into the reservoir is required as a first step into control of eutrophication of the reservoir, and any new developments and industries should require proper wastewater treatment.

5.7.3 Extreme events – Floods, droughts and winds

Extreme events can alter water levels significantly, with floods rapidly increasing the water levels to the full supply level and droughts causing excessive and prolonged drawdown in the reservoir. While floods can obviously be beneficial in maintaining high water levels, they can also degrade the river bed and substrates in the inflowing rivers and cause smothering of the substrate with fresh sediment within the reservoir. The measures to manage changes in the fisheries habitats in the reservoir because of floods have already been described in sections 5.3.4 and 5.6.3., but the design of flood management measures needs to take into account the requirements of the fishery habitats.

It is expected that the number and intensity of windy days at the reservoir will increase with climate change. Winds tend to blow from the southwest to the northeastern shore in the post-monsoon period causing waves to build up. This can create difficult conditions for boats both for fishing and tourism.

ADAPTATION MEASURES

When developing flood management measures such as construction of barriers or retention reservoirs within the catchment (see 5.1.3. and 5.3.4), care must be taken to avoid the main fish spawning grounds and to provide fish passages up and down the rivers and streams where these barriers are built.

An early warning alert system for wind events and the associated build-up of waves should be set up for fishers and tourists using boats.

6 RECOMMENDATIONS FOR SITE MANAGERS

6.1 Components of the plan – off-site management and adaptation measures

6.1.1 Managing the balance of water through the wetland

Table 13 shows adaptation options suggested for ensuring freshwater flows to the reservoir and release downstream.

***Table 13** Adaptation measures for ensuring freshwater flows through wetlands*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Regularly review the changing hydrology and hydraulics of Pong Dam, including the filling and drawdown patterns of the reservoir, with attention to habitat requirements of both migratory birds and fish, as well as inflows and downstream irrigation requirements.			
Construct a network of hydro met stations and silt traps to assess the changing patterns of rainfall and flows in the catchment and the quantities of sediment washed into the reservoir.			
Develop contingency plans on regulation of reservoir water levels in case of flooding events.			
Deploy flood warning systems, e.g., BBMB's existing flood warning and forecast system in the upstream stretches of the reservoir for optimal water management during periods of floods.			
Develop upstream flash flood control measures through a system of flood diversion areas and reservoirs.			
Develop adaptation measures to reduce build-up of sediment in the active storage volume of the reservoir – soil conservation in the catchment and sediment removal in the reservoir.			
Develop adaptation measures to reduce evaporation losses in the reservoir, such as planting tall bushes along the banks of the reservoir and providing shade in certain sections of the reservoir.			
Develop water discharge plans considering the changing climatic conditions of the stakeholder states (Himachal Pradesh, Rajasthan, Punjab and Haryana).			
Promote techniques for more efficient use of irrigation water to help manage the demand for water downstream.			

6.1.2 Catchment management

Adaptation measures for catchment management are described in Table 14.

***Table 14** Adaptation options for catchment management*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Survey of land use and forest cover in the catchment to identify degraded areas at increased risk of landslides and soil erosion	■		
Development of forest conservation plans and watershed management plans, in consultation with local communities	■	■	
Conservation of forest in the catchment to reduce soil erosion and manage runoff and sediment transport		■	■
Development of soil conservation measures for agricultural areas in the catchment		■	■
Formation of local community teams to monitor specific landslide-prone sites and training rescue teams		■	■
Conducting annual remote sensing survey of glaciers in the catchment with field survey of glacial lakes at risk of GLOFs		■	■
Adopting drawdown measures to be adopted at the glacial lakes to prevent risks of glacial lake outburst floods			■
Surveying, redesigning, improving or removing physical structures in the catchment for controlling flows and floodwaters that act as barriers to migrations of fish, especially the Mahseer, for spawning		■	■
Carrying out water quality surveys of rivers and *khads* to assess sources of pollution and high nutrient content and developing the required clean-up and pollution control measures		■	■
Conducting surveys of rare and endangered species and plants with herbal values in the catchment and regular monitoring to assess changes in populations and distribution		■	
Consideration of more resilient varieties of crops and vegetation to be introduced to sustain the catchment ecology			■

6.2 Components of the plan – on-site management measures

6.2.1 Habitat restoration and management

Adaptation measures shown in Table 15 should be implemented for habitat restoration and management.

***Table 15** Measures for habitat restoration and management*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Carrying out a survey of drawdown areas of the reservoir to identify sensitive habitats for migratory birds where sediment is likely to accumulate			
Selection of sustainable methods for removing sediment from sensitive habitats within the drawdown area of the reservoir			
Progressive removal of sediment from the reservoir, safeguarding sensitive habitats for migratory birds			
Restoration and maintenance of shallow water habitats for migratory birds			
Habitat creation by construction of perched wetlands, mounds, bunds and depressions in the drawdown area			
Monitoring of surface and water quality profiles within the deep open water of the reservoir to assess onset of stratification and other water quality issues within the reservoir			
Increasing vegetation cover in surrounding areas of the lake to reduce surface water temperatures and evaporation and erosion			
Considering measures to provide shade in certain sections of the reservoir that are identified as more susceptible to temperature increases and evaporation losses			

6.2.2 Species support and management

The adaptation measures described in Table 16 are recommended for species support and management.

Table 16 *Adaptation measures for species support and management*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Analyse migration patterns in relation to climatic variation, using continued annual censuses of migratory bird species and correlate numbers with numbers overwintering at other destinations in India.			
Carry out regular observations of local movements of migratory birds for roosting and feeding and in response to weather conditions, e.g., winds.			
Consider declaring additional sanctuary areas for roosting and feeding migratory birds.			
Survey the availability of food resources for migratory bird populations visiting Pong Dam.			
Provision of additional food sources for migratory birds, e.g., through growing specific crops in the drawdown to serve as feed for geese and ducks			
Identify and survey conditions in the principal spawning areas of the Mahseer and consider habitat restoration and declaration of fish sanctuaries if necessary.			
Survey Mahseer migration routes up rivers and khads and ensure that they are free from barriers and obstacles that are likely to inhibit migration upstream and downstream.			
Determine the optimum number and locations of fish traps and whether additional licensing or quota measures are required.			
Develop specific fishing rules for when the reservoir water levels are very low under drought conditions.			
Identify areas of refuge for reservoir fish, and establish fish sanctuaries or fish conservation zones, where fishing will be banned throughout the year			
Awareness raising of fishing regulations and fish conservation zones amongst fishing communities Strictly enforce fisheries law and regulations, especially no fishing during spawning season			
Use revenue from the fish catch auction at end of the wet season in each community for restoring degraded fish habitats and key ecosystems for fisheries.			

6.2.3 Livelihood support and management

Table 17 shows adaptation measures that are recommended for livelihood support and management.

***Table 17** Adaptation measures for livelihoods support and management*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Encouraging research-based tourism			
Developing insurance scheme for farmers to cover crop damage caused by migratory birds			
Encouraging diversification of regional businesses that are focused on recreational activities and tourism			
Development, marketing and promotion of eco-tourism at Pong Dam			

6.2.4 Protection against extreme events

Adaptation measures for protection against extreme events are listed in Table 18.

***Table 18** Adaptation measures for protection against extreme events*

Adaptation measure	Immediate (within 1 year)	Short term (over next 2 years)	Long term (over 10 years)
Deployment of flood warning systems in the upstream stretches of the Beas river and *khads* for optimal water management during periods of flood.			
Preparing plans for regulation of water levels in the reservoir in case of flooding events			
Identification of unstable slopes and landslide-prone areas in the catchment and considering large-scale slope stabilisation in critical risk areas			
Identification of critical glacial lakes and deployment of drawdown measures if they are considered to exceed GLOF risk thresholds			
Building capacities of local communities in emergency preparedness to deploy rescue and relief measures during disasters (floods, GLOFs, avalanches, landslides)			
Considering construction of structures for diversion and management of floods, such as dams, to reduce the downstream impacts of flooding events			

6.3 Surveys, research and monitoring

6.3.1 Surveys

Regular surveys are required to collect data on physical, chemical and biological characteristics of the Pong Dam lake, its habitats and species that reflect the ecological condition of the wetland or key indicators of stress that may influence that condition. 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. This will help understand any significant trends and adaptive management.

6.3.2 Research

The Pong Dam lake is relatively under-researched and there is not enough information available for detailed analyses and reviews of the wetland and how it functions. There is considerable scope for further targeted research on the Pong Dam lake, which should try to fill gaps in critical knowledge and information for management and address the shortfalls of previous studies in terms of its ecology, hydrology, biology and socio-economic interactions with the community. Specifically, research is urgently required on:

- The patterns of hydrology and sedimentation, and how the regular filling and drawdown of the reservoir impacts the key habitats for the migratory birds – the mudflats, sand bars and the water quality
- The bathymetry of the reservoir and inflowing rivers and to provide a baseline for assessing sedimentation and erosion changes in the future.
- LULCC in the catchment to identify areas for reforestation and soil conservation
- The habitats used by the migratory birds for roosting and feeding (including shallow water, mudflat zones, shoreline and agricultural cropping areas adjacent to the reservoir) and their feeding requirements for grasses and crops, preferred by migratory birds especially Bar-headed Geese
- Phytoplankton, zooplankton, aquatic vegetation and invertebrates that are essential feed of dabbling ducks such as the Northern Pintail
- Restoration of existing habitats and the design and construction of perched wetlands, mounds etc. in the drawdown area to increase habitat diversity in the reservoir
- Correlation of migratory bird censuses at Pong Dam lake with those at other destinations and overwintering sites to assess the effects of climate change on migration patterns
- Climate-resilient crops that are more drought-resistant and agricultural techniques for soil conservation in the catchment
- Irrigation options for increasing the efficiency of water use in the downstream irrigation schemes
- Revenue generation mechanisms and budgeting for wetland management and implementing adaptation plans

6.3.3 Monitoring

A comprehensive monitoring programme is required for the Pong Dam and Reservoir and its catchment. Consistent, thorough and timely wetland monitoring and assessment programmes are a critical tool for the Ramsar site managers to better manage and protect the wetland resources. An effective monitoring programme allows managers to establish a baseline for the wetland's extent, condition and functions; to detect changes; and to characterise trends over time.

The structure of the monitoring programme should include:

- Long-term measurement of climate parameters, including local air temperatures, (maxima and minima), rainfall, humidity and wind speed and direction, including measurement of extreme events.
- Monitoring of catchment conditions, including forest cover and species composition, identifying gaps in forest cover, areas of increased risk of soil erosion.

- Monitoring of the shrinkage of glaciers in the upper catchment of the Beas river and the development of glacial lakes and risks of GLOFs – this can be done on an annual basis by remote sensing, with field surveys every 5 years.
- Monitoring of the habitat conditions within the reservoir, including:
  a. Water levels within the reservoir are recorded on a weekly basis – this information should be available from BBMB and correlated with the extent of the open water area.
  b. Surface water quality, with a focus on temperature, dissolved oxygen, suspended solids and turbidity and nutrients and phytoplankton dynamics
  c. Water quality of the inflowing rivers and *khads* to assess the extent of water pollution
  d. Depth profiles to assess the onset of stratification of the water column.
  e. Shallow water areas in the drawdown, assessing substrate quality and build-up of sediment especially around the deltas of the inflowing khads.
- Monitoring of keystone species populations, including migratory birds and populations of fishes, especially the Golden Mahseer.
  a. Censuses of the migratory birds visiting Pong dam should be carried out each year, with weekly observations of bird numbers during the migration period.
  b. For Mahseer, identification of the spawning areas in the rivers and *khads* and ensuring both continued access and suitable conditions in these spawning areas.
  c. Regular reporting of fish catches and collecting data on the sizes, weights and species of fish caught each month
- Monitoring the impacts of tourism on the conditions of the Ramsar Site, including encroachment, effluents and 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.

This programme of research, survey and monitoring will allow a targeted design and adjustment of the adaptation measures by identifying areas and habitats where the adaptation 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 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 Stakeholder engagement

6.4.1 Stakeholder engagement in integrated management/adaptation planning for the Ramsar site

There are several key institutional stakeholders responsible for different aspects of the Pong Dam and Reservoir and the Ramsar site. These include the Forest Department, the Himachal Pradesh Wetland Authority, the BBMB and the Fisheries Department. The BBMB has a key role in regulating the flows through the reservoir and the downstream demand for irrigation water and hydropower, which can affect all aspects of the Ramsar wetland. The fishing and agricultural communities and tourism operators are also important stakeholder groups to participate in any management and adaptation plans for the wetland. The roles and responsibilities of the different stakeholders in integrated management and adaptation planning for the Pong Dam and lake are shown in Table 19.

***Table 19** Stakeholders' responsibilities for integrated management and adaptation planning at Pong Dam*

Stakeholder	Rights, roles and responsibilities at Pong Dam	Responsibility for adaptation activities
Forest Department	• Planning of conservation of forests, wildlife and migratory bird habitats • Planning measures related to watershed conservation (reducing forest loss, reducing evaporation losses) • Slope stabilisation planning	• Management of nearby forests, eco-tourism and wildlife; monitoring and evaluation of the flora and fauna. • Plantation of trees to reduce erosion. • Gully plugging and stream bank erosion mitigation. • Implementation of slope stabilisation in the watershed.
HP State Wetland Authority	• Conserve and restore habitats for migratory and resident bird species of the area • Conserve indigenous fish species and make fishery a sustainable livelihood for local fishermen • Harmonise the relation between fishermen, wildlife and farmers • Enhance income of local people by undertaking income generation in the area • Propagate eco-tourism in the area to generate employment • Make tourists more sensitive to the values of nature and wetlands	• Planning and sourcing funds for adaptation measures • Trench to protect breeding colonies of birds • Constructing water-harvesting structures including non-geometrical bunds to create ponds and mounds • Biodiversity conservation plan • Fisheries conservation • Dredging activities • Implementing measures to drawdown from critical glacial lakes
BBMB	• Development of water management plan • Planning flood warning system for Beas • Plans on the regulation of water levels in the reservoir in case of flooding events. • Planning system of reservoirs to control flooding	• Administration, operation and maintenance of Beas Project Unit-I (Beas Satluj Link Project) and Beas Project Unit- II (Pong Dam) in northern India • Regulating the supply of water from the Satluj, Ravi and Beas to the states of Punjab, Haryana and Rajasthan • The regulation and supply of power generated from the Beas Projects. • Implementation of flood warning system
Fisheries Department	• Strategic planning, financial and economic review, preparation and administration of development agreements, analysis and distribution of statistics and scientific information, and analysis and improvement of policy positions on fisheries and aquaculture resource issues • Planning disaster mitigation strategies	• The department will promote, implement, and provide advice on fisheries and aquaculture policies for the support of resource/industry management, growth and development. • Rescue and relief team training and deployment (to mitigate disasters)

Stakeholder	Rights, roles and responsibilities at Pong Dam	Responsibility for adaptation activities
Pong Lake Biodiversity Conservation Society (PLBCS)	• Multi-stakeholder coordination of conservation and management of the natural resources of Pong Dam	• Convening Pong Lake adaptation management committee • Coordination of planning and implementation of adaptation measures between the different agencies
Fishers and local communities	• Licensed fishers have access to fish in Pong Lake and may land catch at recognised sites. • Many fishers are members of established fishing cooperative societies regulated by the state Fisheries Department.	• Involving local communities in plans related to water resource management, conservation of the flora and fauna and disaster mitigation

6.4.2 Stakeholder engagement in monitoring, survey and research

Table 20 describes stakeholder engagement in monitoring, surveying and researching for the Pong Dam lake.

Table 20 *Stakeholders' responsibilities for monitoring, surveying and researching at Pong Dam lake*

Name of stakeholder/ group	Rights, roles and responsibilities at Pong Dam
Forest Department	• Monitoring and evaluation of the flora and fauna • Identification of critical slopes in the watershed (susceptible to landslides)
Wetland authority	• Protection and monitoring of the reservoir (monitoring fisheries and boating, etc.) • Surveying critical glacial lakes
BBMB	• Assessment of demand and supply gap with respect to various stakeholder states • Carrying out research on implementation of the system of reservoirs
Fisheries	• The department promotes, implements and provides advice on fisheries and aquaculture policies for supporting resource/industry management, growth and development. Other activities include strategic planning, financial and economic review, preparation and administration of development agreements, analysis and distribution of statistics, analysis of scientific information, and analysis and improvement of policy positions on fisheries and aquaculture resource issues. • Capacity building workshops on disaster risk • Formation of teams with skilled personnel to mitigate disaster
Fishermen	• Providing insights on the local characteristics of the reservoir

6.4.3 Recommendations for establishing Pong Dam lake management and adaptation committee

The different Pong Dam lake stakeholders, especially the Forest Department, the Wetland Authority, the BBMB, which owns and operates the hydel project, the Fisheries Department and the local communities and fishers, need to be involved in the adaptation planning and implementation and in the research and monitoring required. The Pong Lake Biodiversity Conservation Society (PLBCS) has been established as a multi-stakeholder coordination platform for conserving the biodiversity of

Pong Dam lake under the chair of the Chief Conservator Wildlife (Forest), Dharamsala. An adaptation management committee should be convened to agree and plan the adaptation measures and integrate them into the existing site management plans and hydel operating rules.

OBJECTIVES

- The key objective is to constitute a common platform for wetland management with the aim of optimum planning and management of adaptation measures for the Ramsar Site.
- The platform should take into consideration the roles and responsibilities and the benefits of all the stakeholders and act to resolve conflict in a more resilient/effective manner.

STRUCTURES

- A management committee convened under the Pong Lake Biodiversity Conservation Society, constituted with all the major stakeholders as members, for taking up various issues related to wetland management and adaptation and for matters related to planning, management, fund allocation, etc.
- Every stakeholder organisation, department or stakeholder group should agree on the coordination procedure and may propose the necessary adaptation measures for which they will be responsible.
- There should exist a special platform for local community representatives and outreach to the local communities
- These meetings can take place in the District Collector’s office, and the outcomes should be conveyed to all the stakeholders.

PROCESS

- A start-up workshop with all major stakeholders should be convened for fine-tuning and effective collaboration between different stakeholders. The outcome of such a workshop will form the basis on which to propose to the government the formation of a committee under the Pong Lake Biodiversity Conservation Society. This will further facilitate the formulation of the integrated adaptation and management plan.

TIMING

- The components of the adaptation plan listed in sections 6.1. and 6.2 indicate the requirement of monitoring and evaluation of adaptation measures undertaken by different stakeholders at short-, medium- and long-term time scales.

7 CONCLUSION

This report provides an assessment of the vulnerabilities of the Pong Dam lake and its key assets to the projected effects of climate change, increased rainfall in the monsoon period and decreased rainfall in the dry seasons, coupled with a general increase in temperature throughout the year. The assessments show that these seasonal changes will be exacerbated by increases in the frequency and intensity of extreme events of flooding, landslides, glacial melt and GLOFs.

As a man-made hydroelectric and irrigation dam, the reservoir and its surroundings created attractive habitats as an important staging point for large numbers of migratory birds. The operation of the dam in providing irrigation and water supply to downstream states, with regular monsoon filling and drawdown during the dry season, are critical to the continued success of the site in attracting migratory birds, especially Bar-headed Geese. The attractiveness of the site for migratory birds visiting and remaining in the site over winter depends on the suitability of the habitats in providing roosting security and food from aquatic and terrestrial food sources, including agricultural crops.

Climate changes bringing increased risks of floods, soil erosion from the catchment and sediment build-up in the reservoir and changing the demand for irrigation water downstream are likely to change and degrade the reservoir and shallow water habitats in the drawdown area around the reservoir. Those changes may make the site less attractive to the migratory birds in the future, worsening the declines in the endangered fish species such as the Golden MahseerMahseer and altering the productivity of fisheries livelihoods for the surrounding communities. Such changes may also reduce the attractiveness of the site for eco-tourists.

A range of adaptation measures has been presented as options for dealing with these issues, some of which have already been included in the current management plan. Others will require coordination with the hydel operations. This climate change assessment serves to reinforce the need for these management measures to be carried out with due care and attention, for example, the management of floods caused by glacial melt, storm events and landslides. Increased rainfall in the large and sensitive catchment is likely to increase soil erosion and so catchment management with reforestation, soil conservation and sediment trapping will become more important. Careful desilting of the reservoir and restoration of habitats used by the migratory birds for roosting and feeding, including creating greater diversity in the habitats in the drawdown, e.g., through the construction of perched wetlands, depressions, and mounds. Special crops may be grown in the drawdown area as additional feed for the geese and other migratory birds, and insurance can be provided to the farmers for crop damage by these birds. FCZs within the reservoir and in the rivers coming into the reservoir will help protect the spawning areas for the productive fish populations.

The feasibility and planning of these proposed adaptation measures will require appropriate surveys, research and design, followed by ongoing monitoring to ensure effectiveness. Implementation of all or some of these measures will need the coordination and cooperation of the different stakeholders involved with the Pong Dam lake. It is recommended that an adaptation management committee involving all the stakeholders be set up under the PLBCS to agree on the measures that should be implemented over the next decade to protect the site against climate change.

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9 ANNEXES

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

9.1.1 Impact and vulnerability assessment

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

The climate change impact and vulnerability assessment follow a recognised pattern of assessing the exposure and sensitivities to the climate change threats and the likely impacts that may result. When combined with the adaptive capacity of the target asset or system, a ranking and analysis of their vulnerability can be made. The operational climate change impact and vulnerability assessment process involve six main steps as shown in Figure 28.

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

Figure 28 *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 was being assessed. The scope described the limits of the planning task, including the time horizon, geographical area, sectors or assets to be covered and availability of resources 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 of the upstream catchment and the dependence of the downstream areas on water flowing through the Ramsar Site (see Figure 29 to 32).

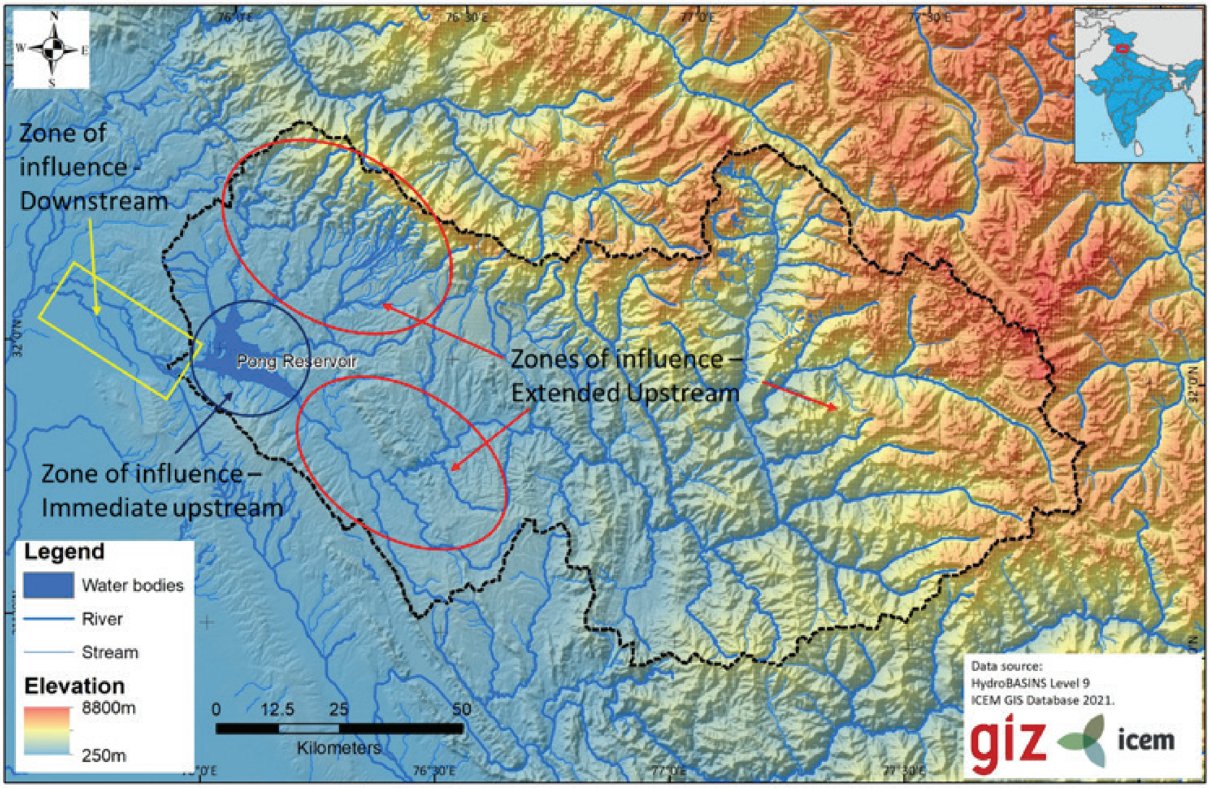


Figure 29 Pong Dam lake and the zones of influence within its catchment

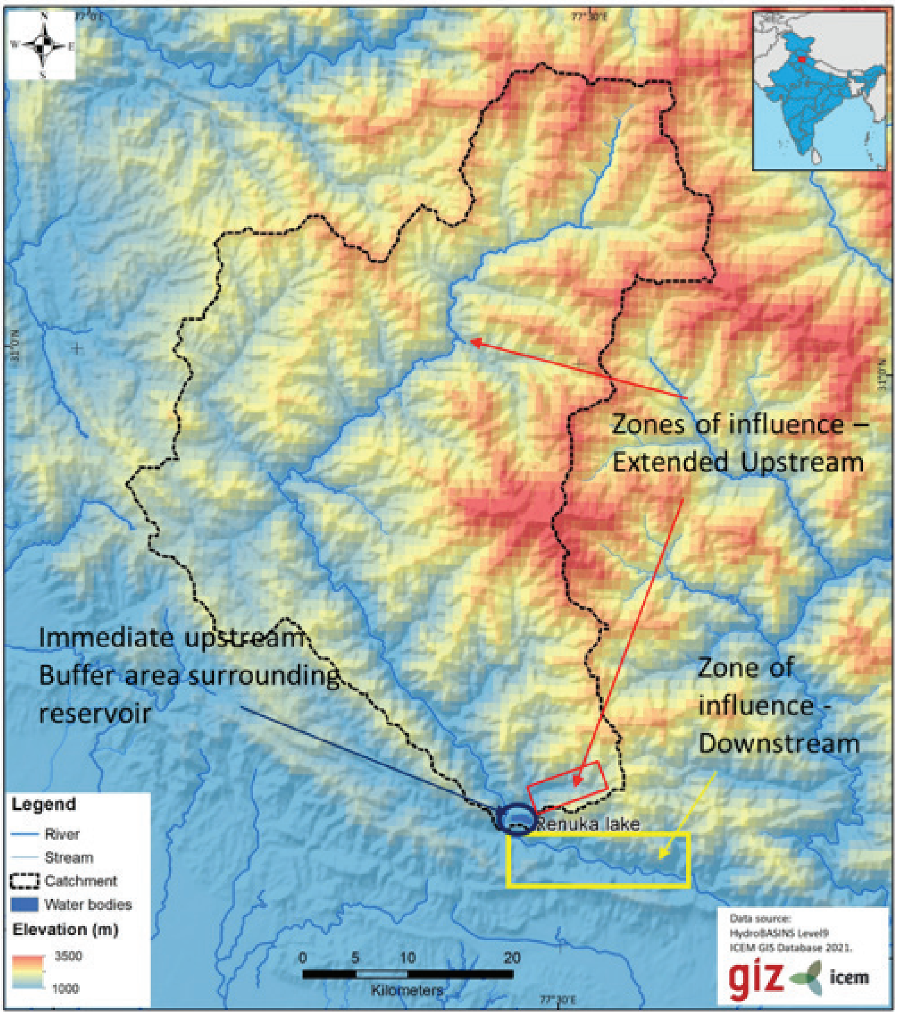


Figure 30 Renuka Wetland and the zones of influence within its catchment

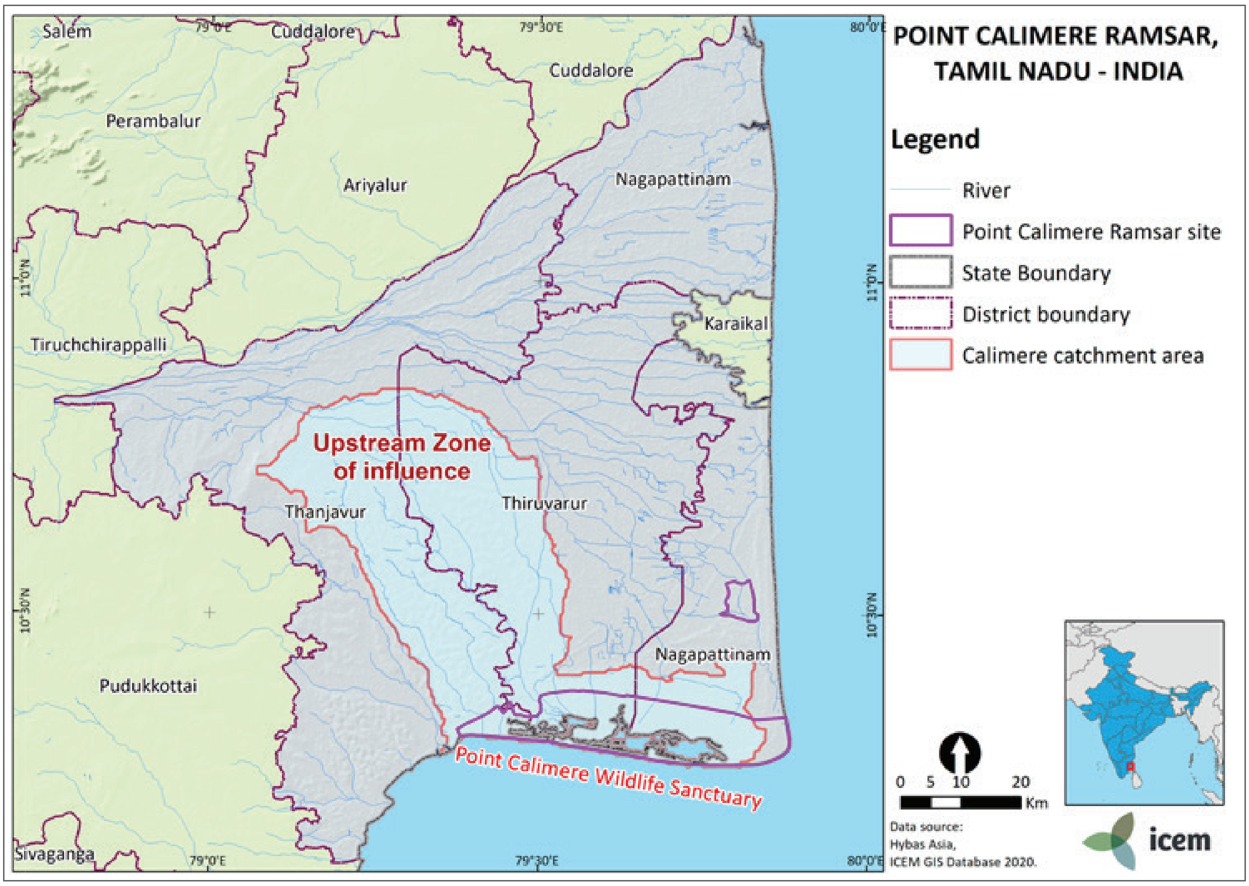


Figure 31 Point Calimere Bird and Wildlife Sanctuary and its upstream zone of influence

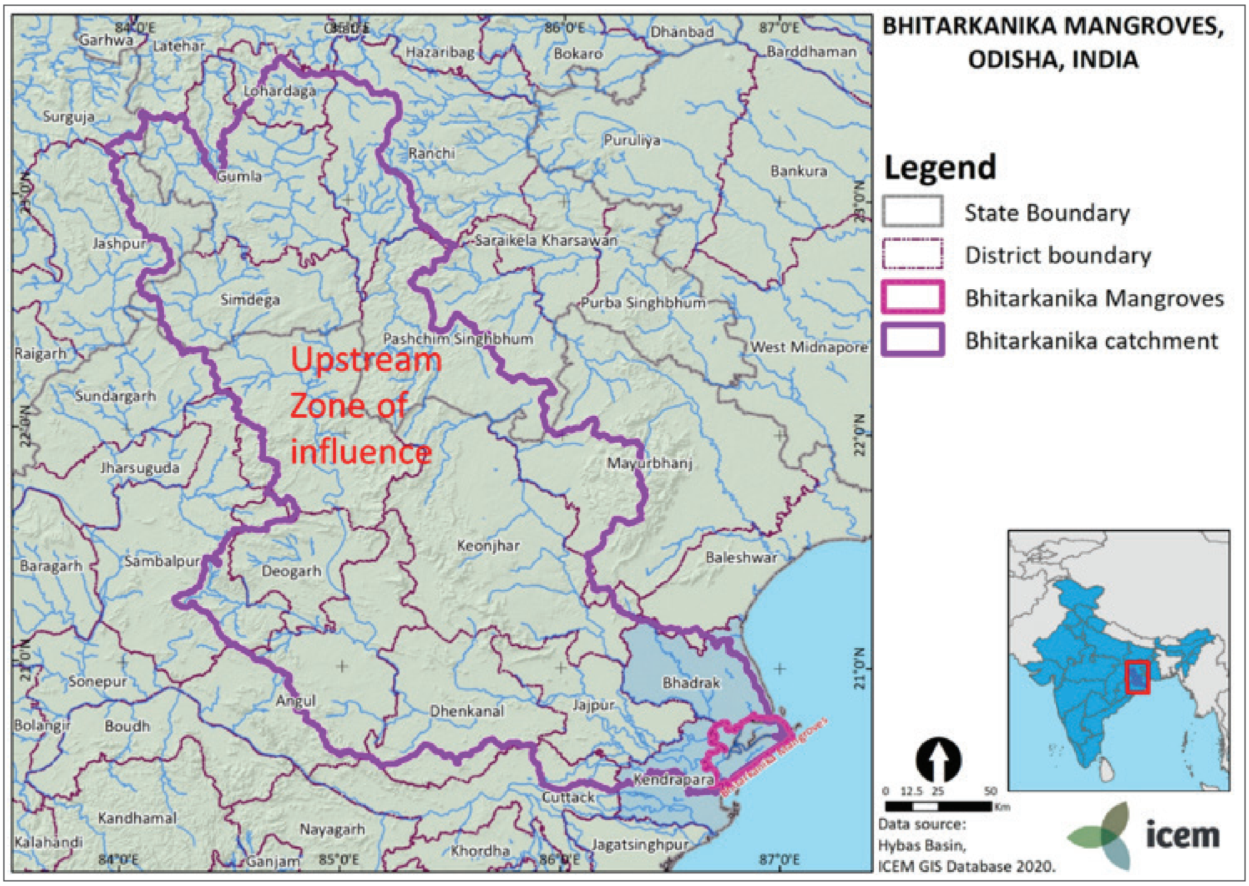


Figure 32 Bhitarkanika Mangroves and its upstream zone of influence

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

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

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

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

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

TARGET ASSET SELECTION

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

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

The individual assets fall within the following categories:

- **Physical infrastructure elements:** that determine the wetland character – we do not select the hydrology or chemical characteristics, e.g., the salinity profile, of the wetland because these are likely to change with the climate and directly impact the habitats and species (i.e., they become part of the threat). However, we may choose infrastructure regulating flows and water levels in the wetland or shoreline protection infrastructure as appropriate.
- **Key habitats:** that define the wetland ecosystem – we should select the predominant habitats within the wetland.
- **Keystone species:** for those habitats, without which the habitat would change or which are essential for the maintenance of ecological processes, e.g., the main plant species within the habitat, food web species, breeding species and top carnivores
- **Important wetland species for Ramsar site definition:** which are the justification for international designation and conservation and protection areas. These may not be keystone species but may already be under threat and are often flagship or iconic species.

- **Ecosystem services:** important for local people using the Ramsar Site, these may relate to provisioning services such as fishing, livestock, agriculture or salt production or cultural services such as festivals, recreation and tourism.

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

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

One or two assets from each type were chosen, considering the ones that score highly on the criteria as shown in the scoring sheet (Table 21).

Table 21 *Scoring sheet to aid target asset selection*

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

The baseline assessment describes the past and existing situations and the trends and drivers affecting the target system/asset. It involves documenting climate and hydrological change projections that will affect the system/asset and surrounding area and compiling a climate change opportunities and threat profile. Usually, the process requires field missions to relevant locations and consultation with stakeholders, including local government officers, site managers and affected communities. The main components of the baseline description include (Figure 33):

- 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 33 *Components for the baseline assessment*

For this assessment, the descriptions of the past and existing situations and conditions at the four Ramsar sites were derived from existing information, the literature, surveys and reports. The main references include:

- Ramsar Site Information sheets, which describe the sites and the criteria used for designation
- Subsequent surveys and monitoring of the flora and fauna at the sites, e.g., as carried out using the Wetland Inventory, Assessment and Monitoring System (WIAMS)
- The hydro-ecological assessments were carried out for all 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:

- Descriptions of key wetland ecosystem functions and habitats
- A species/systems database, including climate tolerances
- Descriptions of impacts of past extreme events (including results of participatory flood mapping with stakeholders)
- Identification of 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 two key elements: (1) analysing and documenting past extreme events and trends and (2) developing climate change and hydrology projections against various scenarios (Figure 34).

Figure 34 *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, including floods, storms, landslides and droughts, 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 extend the assessment beyond the primary boundary of each Ramsar Site, including upstream and downstream zones of influence (Figure 29 to Figure 32).

9.1.4.2 Climate change and hydrological projections

Using the latest downscaled climate models and scenarios, projections and maps were developed for the seasonal temperature and rainfall changes, the hydrological change and the likelihood and intensity of climate events in each catchment of each site. For coastal wetlands, the sea-level rise and storm surges are critical, affecting the sustainability of the mangroves at the sites, and 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 the available assessments of the four Ramsar sites that had been conducted recently by the government and GIZ's consultants, including:

- Hydrological modelling reports for each of the Ramsar sites[13] [14] [15] [16]
- National assessments made in 2020 by the Ministry of Earth Sciences (MoES)[17] and in 2010 by the Indian Network on Climate Change Assessment (INCCA)[18].

HYDROLOGICAL MODELLING REPORTS

The hydrological report for Pong Dam lake is a final report, recently developed by a GIZ consultant. It provides a detailed climate change assessment for the whole Pong basin that used the Coordinated Regional Climate Downscaling Experiment South Asia (CORDEX – SA) with RCP4.5 and RCP8.5 scenarios. The ensemble mean of three regional climate

[13]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.
[14]ACWADAM and PSI, 2020. Renuka Wetland Hydrogeological Assessment, Management Strategies and Capacity Building. Interim Report. Prepared for GIZ.
[15]Institute of Technology and Sciences, 2020. Hydro-ecological assessment for integrated management of Point Calimere Ramsar site. Interim Report. Prepared for GIZ.
[16]Chilika Development Authority, 2020. Hydro-ecological assessment for integrated management of Bhitarkanika Ramsar site, Odisha. Interim Report. Prepared for GIZ.
[17]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.
[18]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.

models (RCM), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO), was used for the analysis. The report provides valuable projections of changes in precipitation (in %), and maximum and minimum temperatures (in °C) across the Pong basin for 2021–2050 and 2071–2100, with respect to a baseline period of 1981–2010. Unfortunately, it does not contain the actual figures of the precipitation (i.e., in mm) and the temperature (in °C) for the baseline as well as future projections, which are important to the vulnerability assessment process.

Such detailed assessments are not available for the other Ramsar sites. The hydrological reports provided for Renuka Lake, Bhitarkanika Mangroves and Point Calimere are interim reports. They contain some useful information on the 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. In contrast, the projections at Bhitarkanika, as described in the interim hydrological report, were based on an ensemble of three other climate models, including HadGEM2, GFDL, and MIROC (conducted by Central Water Commission – CWC in 2015).

NATIONAL ASSESSMENTS

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

Another national climate change assessment (2030s), with respect to a baseline period 1961–1990, was conducted in 2010 by the INCCA, as part of the National Action Plan on Climate Change (NAPCC). Indian states then developed their own SAPCC 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, and 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 the Himalaya will increase 20–40%) that would not be suitable for specific site-based assessments.

ICEM'S SITE-BASED ASSESSMENT METHOD

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

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

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

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

Box 1 *About WorldClim data and RCP 8.5*

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

Step 1: Initial selection of GCMs

The initial selection was based on the evaluation of climate models that has been used in recent studies in India (i.e., CORDEX-SA models used for Pong basin and the national assessment in 2020). From the evaluation, 10 common GCMs used in these studies that demonstrated 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 the projections reported in the recent studies, where relevant (i.e., projections reported for Pong basin and in the national assessment in 2020) (Figure 35 and 36). From the comparison process, three GCMs that produced the most consistent projection results with current studies were then selected, including CCSM4, HadGEM2-ES and MIROC-ESM**.** Brief descriptions of these models are shown in Box 2.

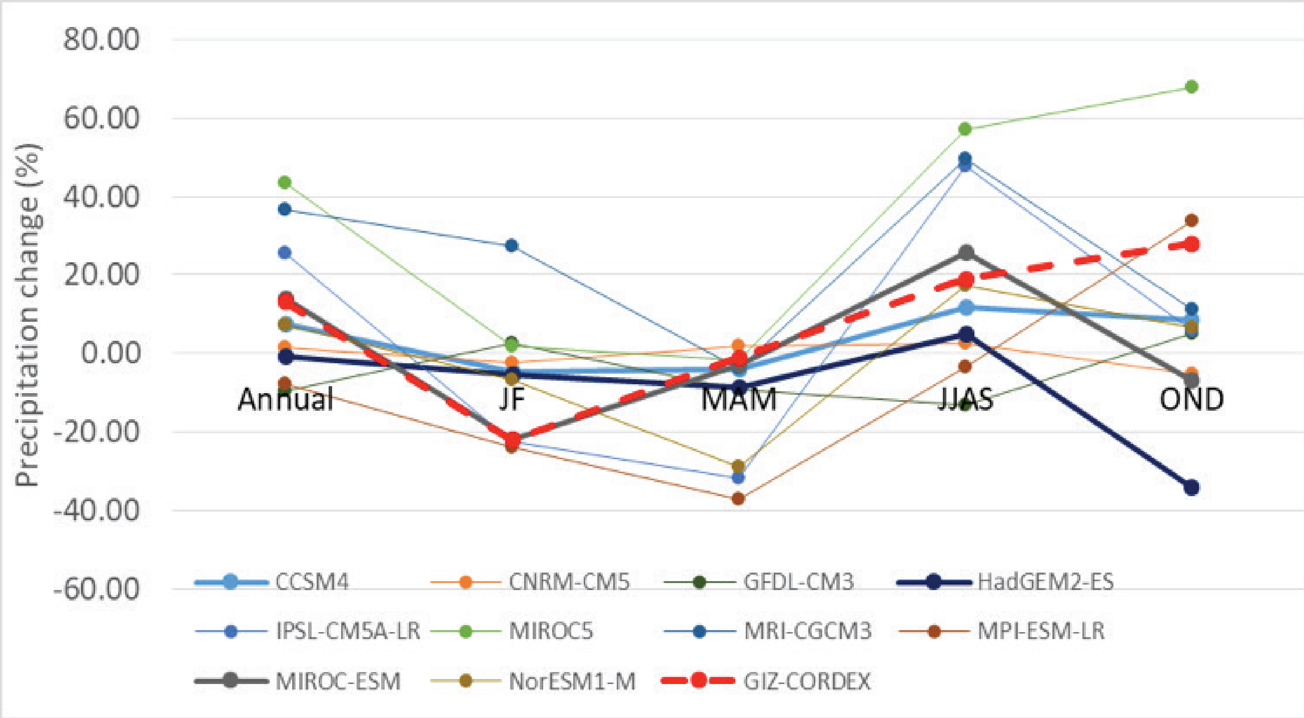


Figure 35 *Changes in precipitation in Pong basin (2050s) derived from the 10 GCMs in comparison with results reported by CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

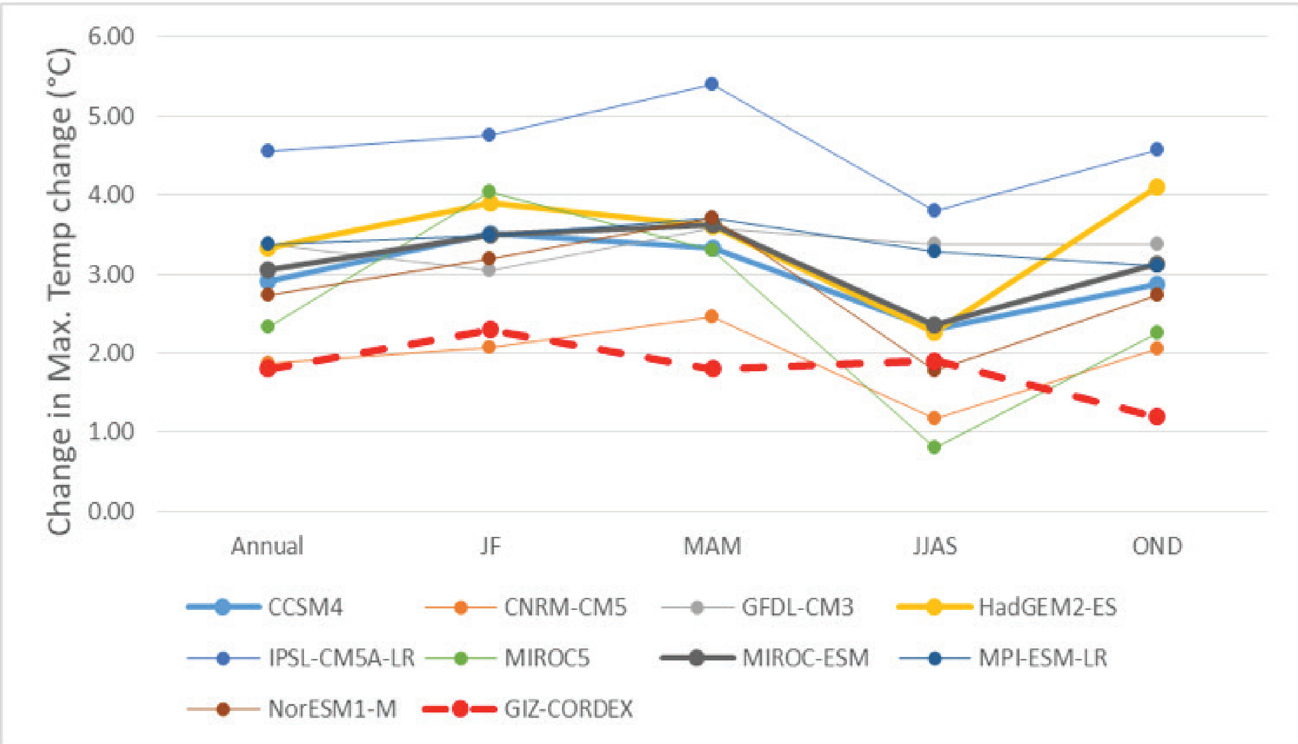


Figure 36 *Changes in temperature in Pong basin (2050s) derived from the 10 GCMs in comparison with results reported by CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

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

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

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

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

Step 3: Climate change projections for the Ramsar sites

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

HYDROLOGIC ASSESSMENT AND IMPACT OF HYDRAULIC STRUCTURES

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

9.1.5 Assessment of climate change impacts

For each of the Ramsar Sites and the targeted assets, the exposure, sensitivity, impact and adaptive capacity were defined using the baseline and climate threat modelling results and CAM matrix support tools. All of the wetland ecosystems and species will be affected by climate change, depending on their sensitivities to the changes, their abundance, their interdependence with other species and elements in their environment and their ability to adapt. 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 be 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 39 shows the parameters and issues that were considered in carrying out the impact and vulnerability assessment at the four Ramsar Sites.

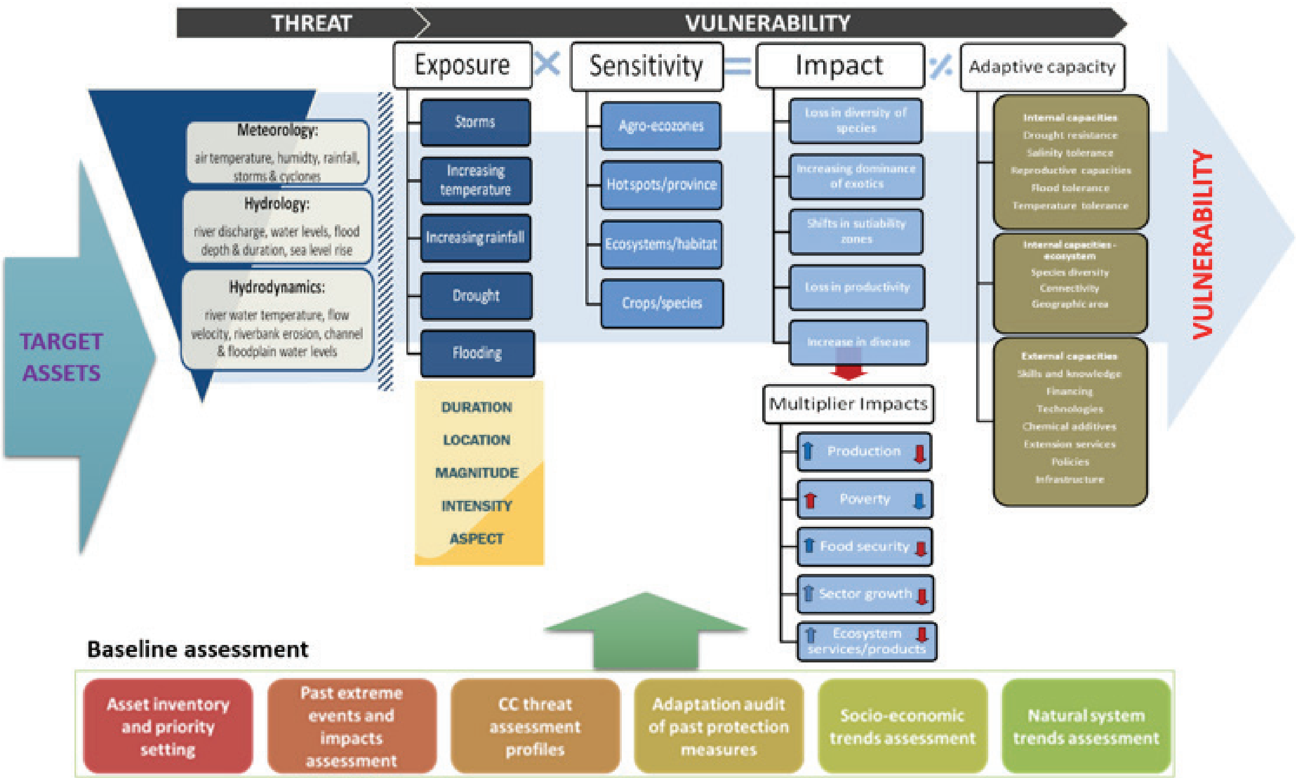


Figure 37 *Illustration of parameters and issues considered in the CAM baseline and vulnerability assessment process*

EXPOSURE

The rating system for exposure and other parameters used in 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 38).

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

***Figure 38** 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 37).

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

***Figure 39** 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 it, which limits its population and the possibility of spreading elsewhere.

Rare or threatened: The species or ecosystems may be classified as rare or threatened, e.g., on the IUCN Red List, which would indicate the 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 its seeds are 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 rises, day length, rainfall at the start of the monsoon and increased flows in rivers, especially for breeding or migration. If these are changed, they may be more sensitive.

The CAM tools at this stage consist of a Vulnerability Assessment Matrix as illustrated in Table 22. 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 23.

Table 22 *Vulnerability Assessment Matrix for recording and annotating exposure, sensitivity and impact scoring*

Threat Category	Details of threats	Impact Assessment				Adaptive Capacity	Vulnerability (impact x adaptive capacity)
		Exposure	Sensitivity	Impact Level (exposure x sensitivity)	Impact Summary		
Seasonal Changes							
Temperature Increase							
Rainfall							
Extreme event changes							
Coastal flood events							
Upper catchment flash flood							
Storm surge							
Large scale extreme level flooding							
Sea level rise							

Table 23 *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 22). 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 of wetland habitats, species and ecosystem services was to determine their adaptive capacity and that of the managing organisation or community to avoid, prepare for and respond to the impacts.

The adaptive capacities were identified as (1) the internal capacity of the species, (2) the internal capacity of the ecosystem and (3) the external capacities of managing organisations and user communities. These are shown in Figure 40. The scoring system for adaptive capacity for external capacities is shown in Figure 41.

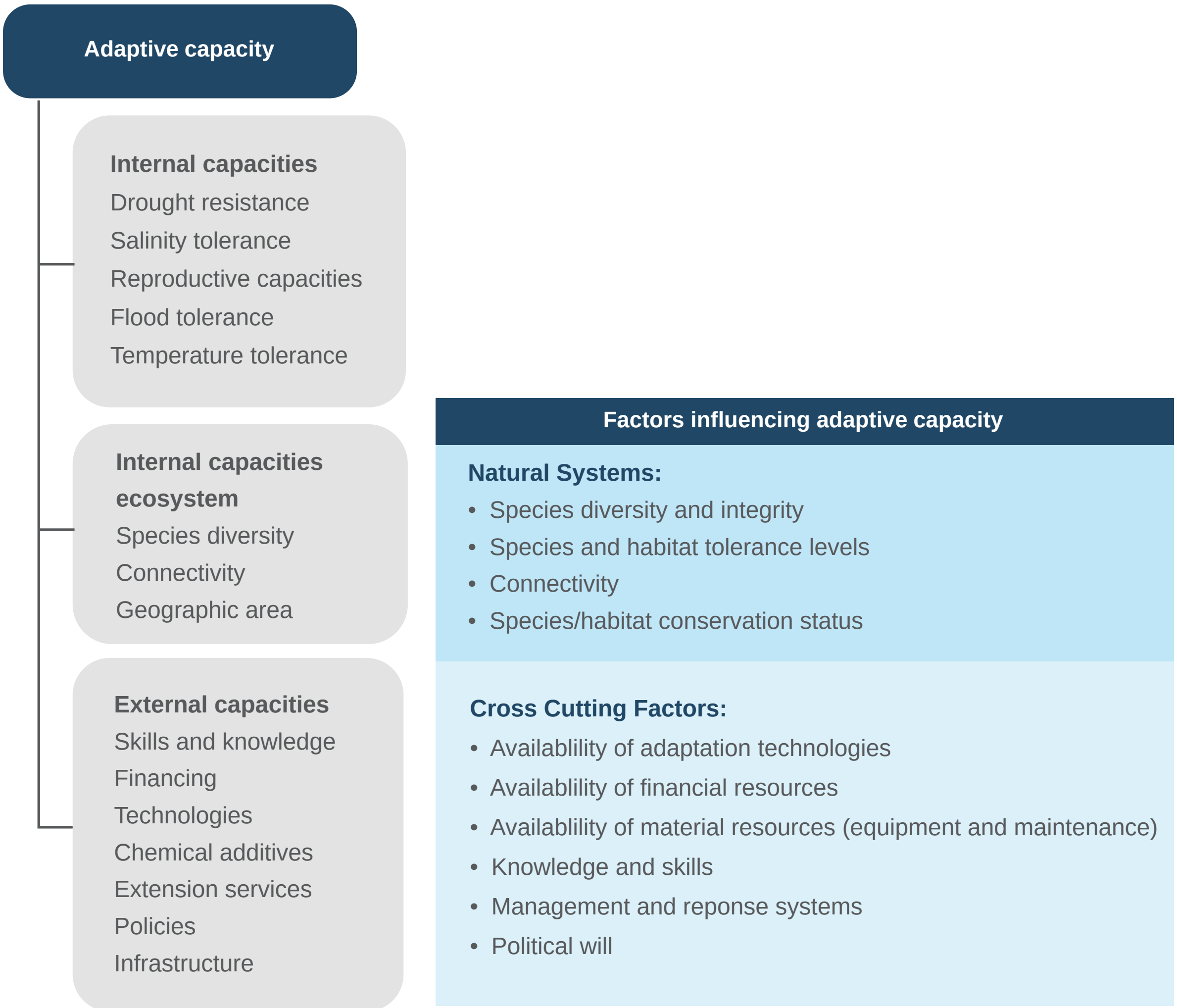


***Figure 40** Adaptive capacities and influencing factors*

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

Figure 41 *Adaptive capacity scoring for external capacities*

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

The next step was to determine the final **vulnerability score.** This was done by considering the impact and adaptation capacity together. With increasing severity of the impact, the 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 24.

Table 24 *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 sites.

9.1.7.1 Shifts in climate, ecology and ecosystem services

Because of climate change, there are likely shifts in the regular climate patterns that will, in turn, lead to ecological and ecosystem service shifts in both space and time as illustrated in Table 25.

Table 25 *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
Seasonal shifts (time) • **Onset and end** • **Variability**	Body size changes – warming associated with decreased body size	Reduced availability and access to NTFPs
	Genetic changes (eg tolerance shifts; stress proteins)	Reduced water availability
	Accelerating loss of populations & species in hot spots (extreme temperatures, coupled with drying – a significant driver of biodiversity loss)	Diminished regulatory and habitat services
Extreme events shifts • **Extreme event shifts – intensity, regularity, location** • **Micro events – eg flash flooding and soil loss in uplands** • **Macro events – eg saline intrusion in Delta; cyclone landfall**	New 'problem' species entering communities	Reduced pollination and pest control
		Reduced soil organic (carbon) content
		Reduced soil microfauna and flora
		Systems requiring more intensive inputs

Geographic shifts are illustrated in Figure 42, showing how the lower (green) area of the original habitat is no longer a suitable habitat and shifts towards the upper (blue) area. Temporal shifts are illustrated in Figure 43, with climate change increasing the frequency (number of days) of increased maximum temperature, which could be indicative of the duration of heat waves.

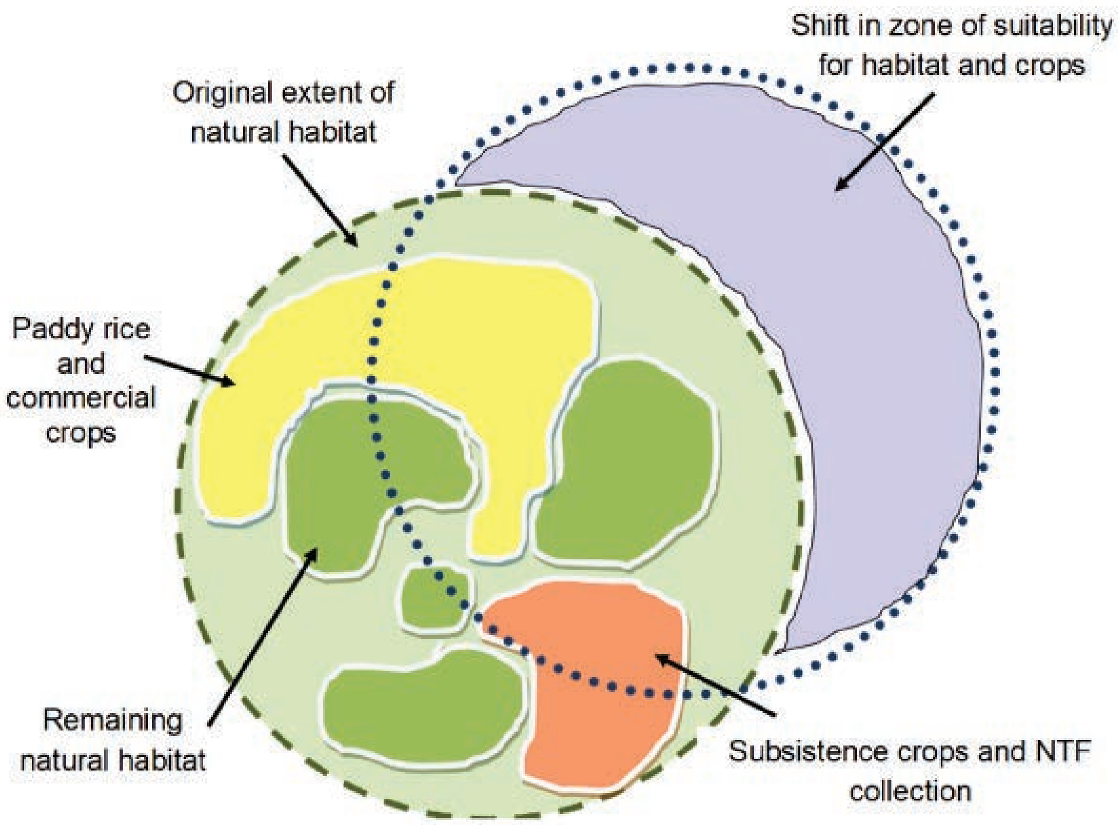


Figure 42 *Illustration of a geographic shift in suitability of habitat*

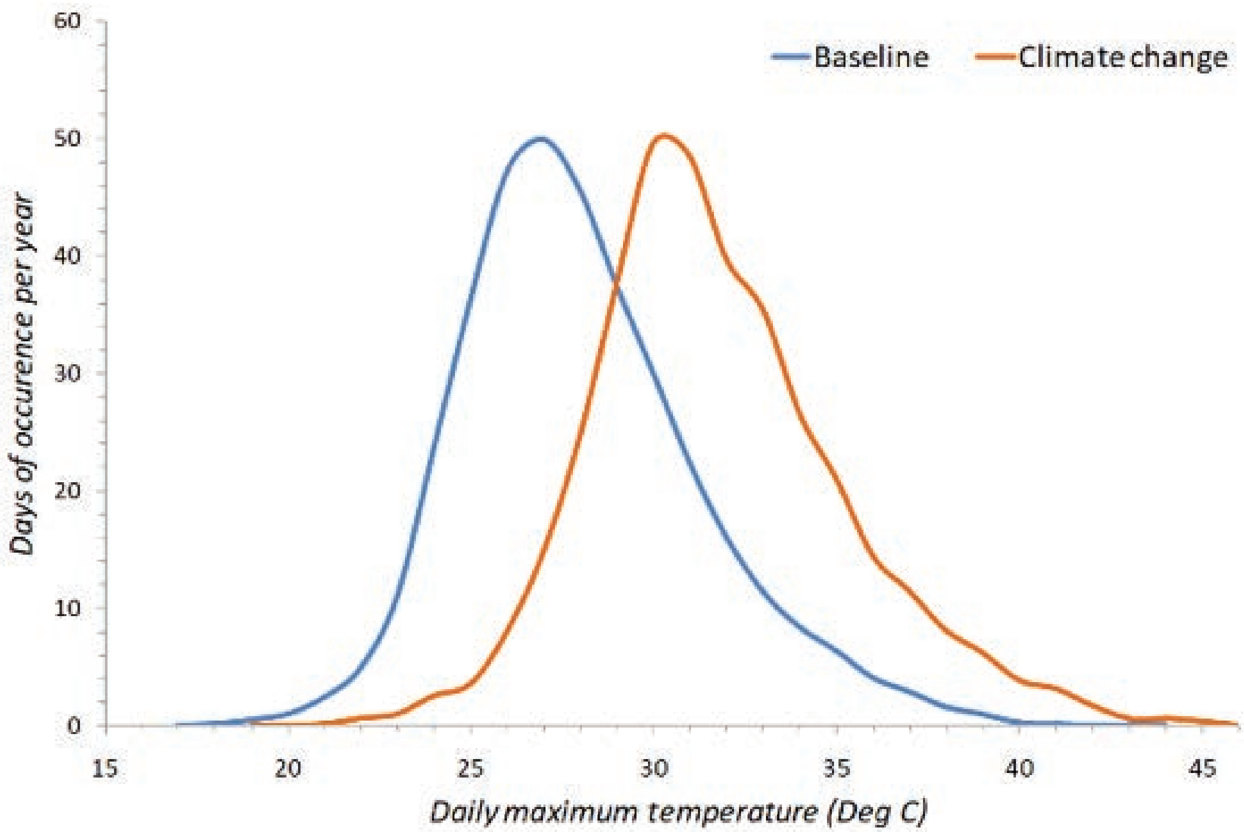


Figure 43 *Temporal shift increasing number of days with increased maximum temperature*

9.1.7.2 Species and habitat comfort zone analysis

Comfort zones are where species and ecosystems experience the most suitable growing conditions in terms of the range and timing of temperature and rainfall. ICEM defines comfort zones to include 50% of the baseline variability in temperature and rainfall for typical months, seasons and years about the mean. In Figure 44, 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.

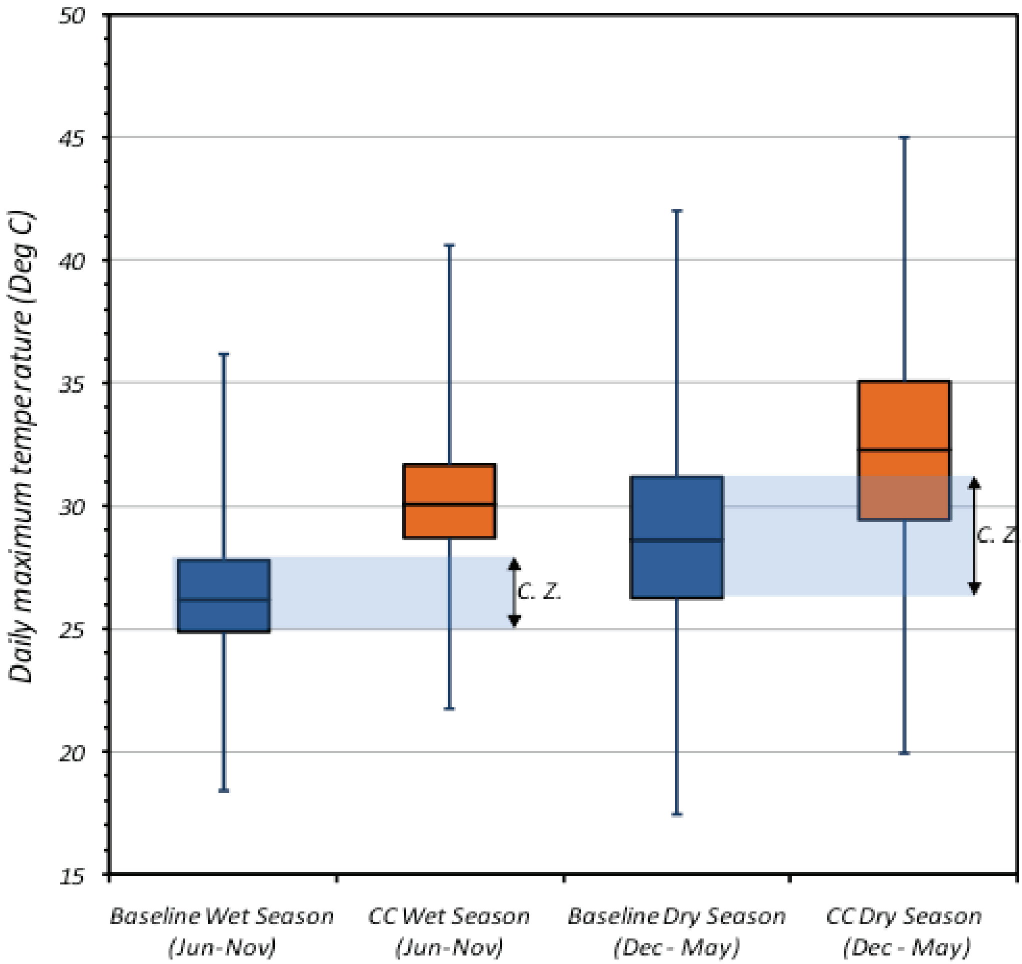


Figure 44 *Illustrating comfort zones: Daily maximum temperatures in the wet and dry seasons*

Each habitat and species has different seasonal comfort zones for temperature and rainfall, and we try to define these for the target assets with references to the literature on their natural range, their growing requirements and breeding cycle requirements, for example. There are databases such as the FAO Ecocrop database[19], CABI Forest Science database[20], FishBase[21], the Reptile database[22], the IUCN Red List data[23] and the India Biodiversity database[24], which may be used to source this information for the species or similar surrogate species (if detailed species-specific data are not available).

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

9.1.7.3 Geographic hot spots

The identification of geographic hot spots or areas that may be highly vulnerable to climate change (e.g., those projected to experience much hotter temperatures or drier climates than the surrounding areas may also help in the assessment of species vulnerability and indicate areas where shifts and changes in vegetation are likely to occur). Examples of India-wide hot spot identification are shown in Figure 45, and Figure 46 shows how vulnerability hot spot maps can be developed from increased temperature impacts.

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

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

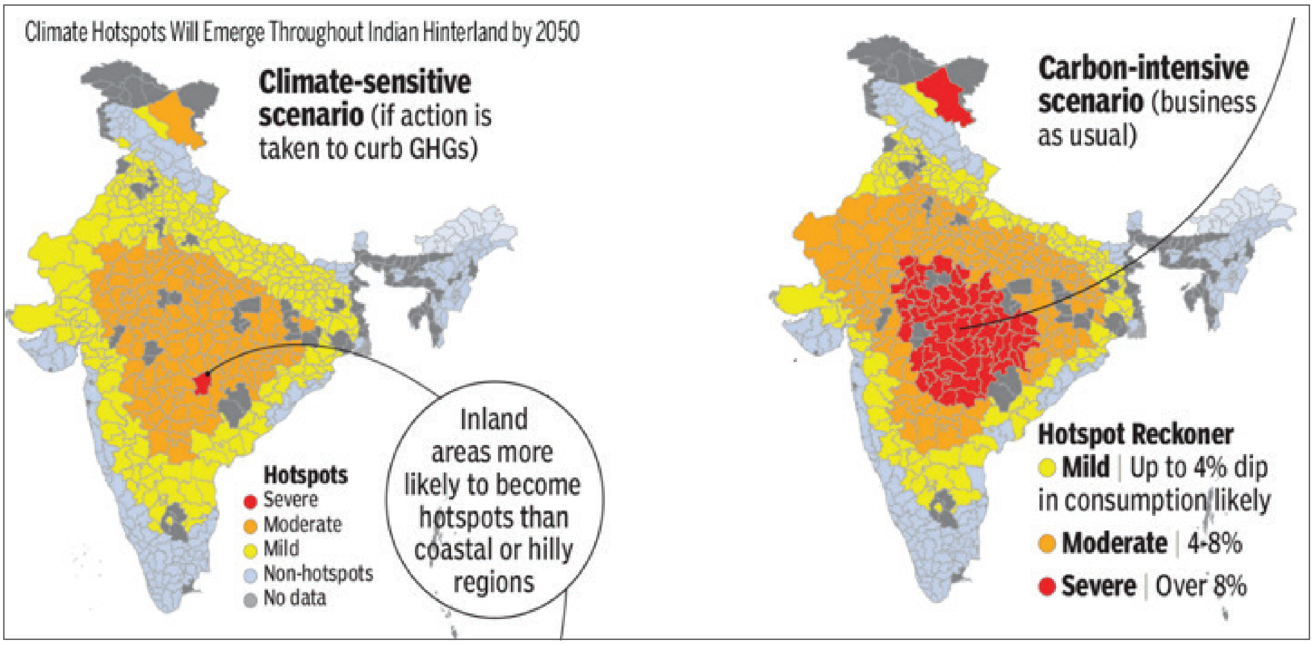


Figure 45 *Examples of India-wide temperature-defined hot spots under two climate change scenarios (Source: Mani et al. 2018)*

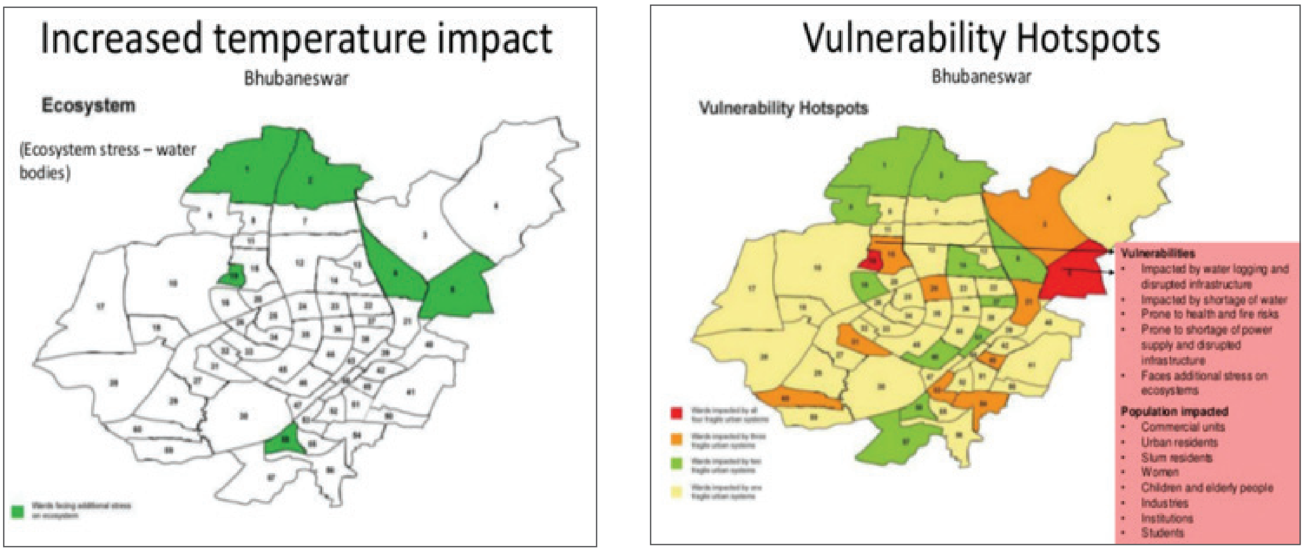


Figure 46 *Exampale for developing vulnerability hot spots from maps of increased temperature impact (Source: Dr W G Prasanna Khumar, Centre for Climate & Disaster Management, https://www.slideshare.net/wgpkumar/climate-change-and-india)*

9.1.7.4 Climate change and ecological zones

The zoning of ecological and climate characteristics provides a useful visual method for comparing areas with similar characteristics and for noting climatic shifts. Ecological zones may have detailed biophysical descriptors of elevation, temperature, rainfall, landform, natural system descriptors with vegetation, soils, agricultural, livestock and fisheries profiles. For instance, Figure 47 shows the zones for soil moisture content in Odisha on a particular date.

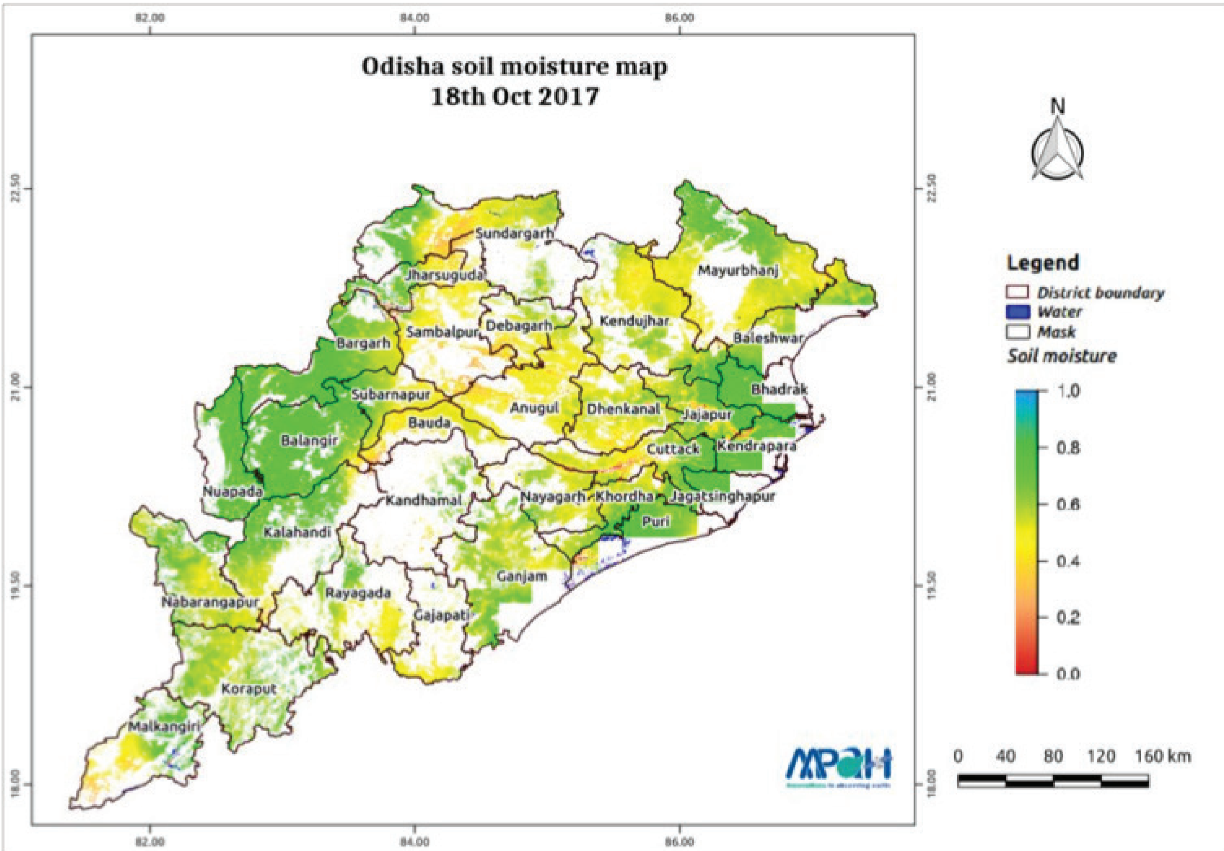


Figure 47 *Odisha soil moisture zonal map (Source: Aapah Innovations, http://www.aapahinnovations.com/soil-moisture-map-state-odisha-2/)*

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 (GDD), reflecting latitudinal and altitudinal temperature gradients; (ii) the aridity index (Trabucco et al., 2008), which forms an expression of plant-available moisture; (iii) temperature; and (iv) potential evapotranspiration seasonality, which express both seasonality and continentality (Metzger, 2013). The two Ramsar sites in Himachal Pradesh have greater variations in the 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 the annual precipitation in the Pong basin (Figure 48). These variables are used in overlays to assess the potential changes in bioclimatic zones.

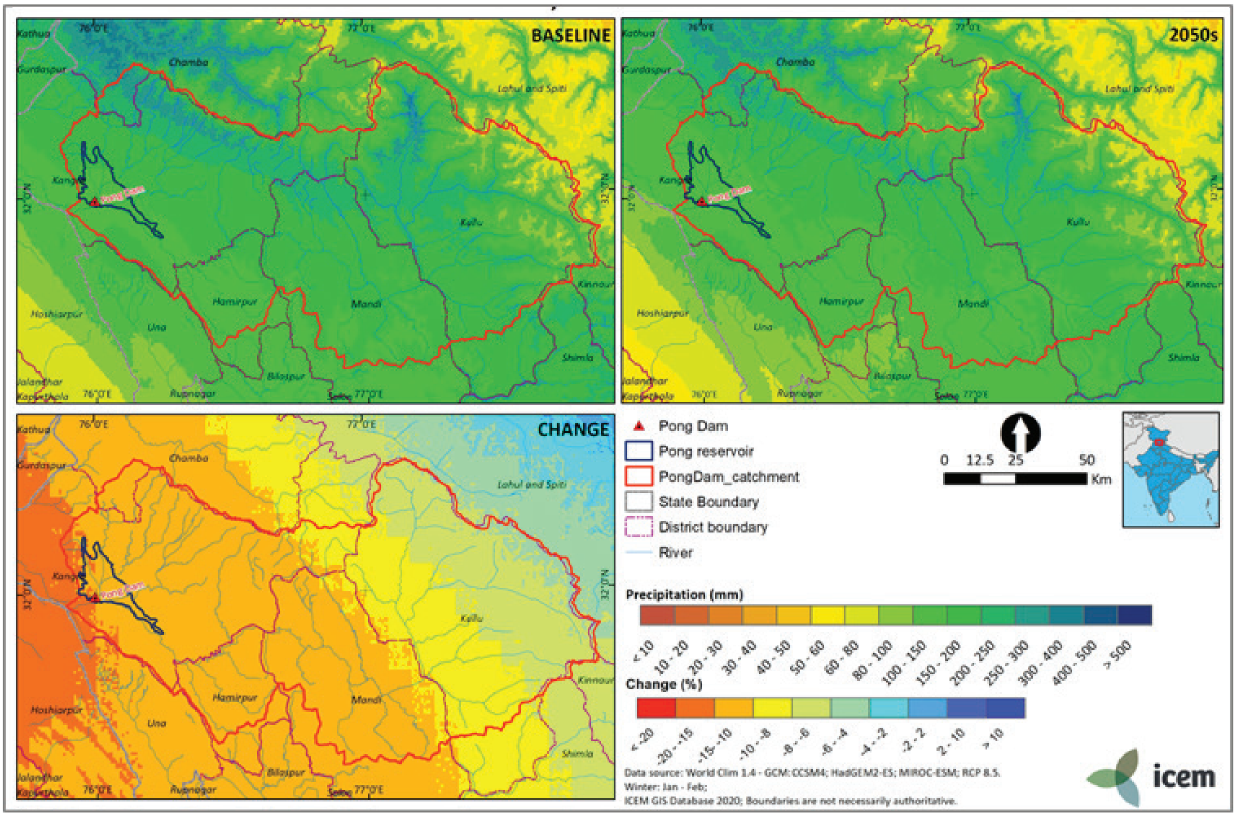


Figure 48 *Climate change zonal map – changes in annual precipitation in Pong basin*

9.1.8 Ecosystem-based adaptation planning

Adaptation measures can be taken to address different stages of the vulnerability assessment cycle. Threats of climate change are best addressed through mitigation measures, by 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 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 49).

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

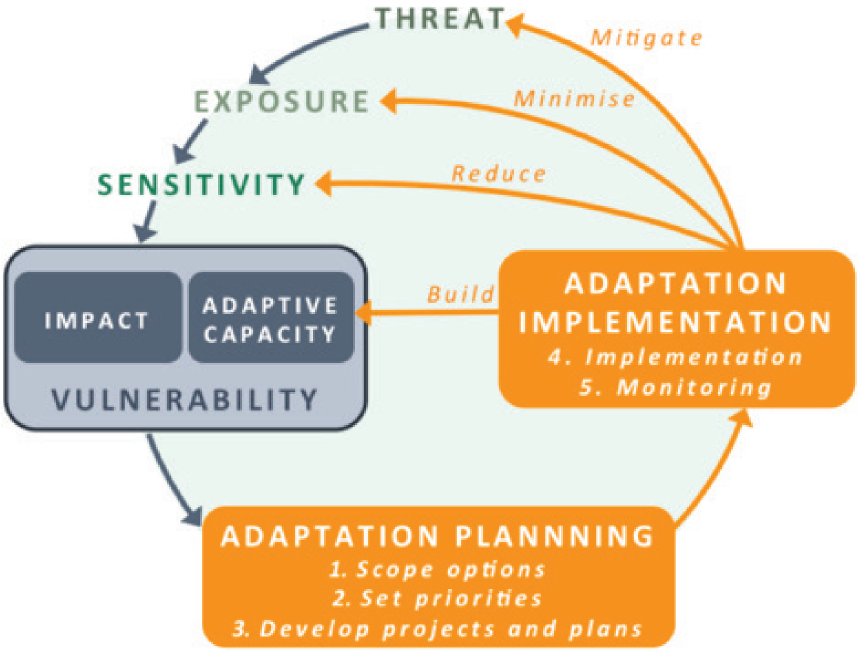


***Figure 49** Schematic of adaptation options to address climate change impacts on an asset*

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

The CAM Adaptation Planning builds on the vulnerability assessments to develop a range of options and then determine priorities (Figure 48). In situations of limited resources, it is not possible or necessary to do everything at once – choices need to be made on what is feasible now and what can be left to later planning cycles.

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

***Figure 50** CAM Adaptation Planning process*

Table 26 Ecological principles and adaption options for individual protected areas or supporting landscapes

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

(Source: IUCN, 2016)

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

The effectiveness of adaptation options is the degree to which each adaptation option would be successful in avoiding or reducing the negative impacts of climate change on the target system and enhancing any benefits and opportunities that may arise. Three questions that can be asked to assess effectiveness are:

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

The options may then be scored for both feasibility and effectiveness in a range similar to that of vulnerability as shown in Table 27 and prioritised using the adaptation matrix of feasibility and Table 28.

Table 27 *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 28 *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 used for major infrastructure projects – an optional step that we do not take 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 be recorded in detailed footnotes.

Table29 The Adaptation Matrix – an example from assessment of an irrigation system in Nepal

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

9.2 ANNEX 2 – SUMMARY OF RECENT CLIMATE CHANGE ASSESSMENT FOR PONG BASIN

For the Pong basin, a recent climate change analysis has been conducted by a GIZ consultant (INRM Consultants)[26]. This analysis used the Coordinated Regional Climate Downscaling Experiment (CORDEX) South Asia with RCP4.5 and RCP8.5 scenarios for modelling climate data on precipitation and maximum and minimum temperatures for the Pong basin. Climate extreme indices have been analysed for the Pong basin and districts falling within the Pong catchment, for baseline (BL, 1981–2010), mid-century (MC, 2021–2050) and end–century (EC, 2071–2100). Projected changes in precipitation and maximum and minimum temperatures were assessed for the study area. The resolution of the projected climate data is at a grid-spacing of 0.5° × 0.5° for IPCC AR5 scenarios, namely, RCP8.5 (a scenario of comparatively high greenhouse gas emissions that does not include climate policy interventions) and RCP4.5 (a moderate emission scenario assuming climate policy interventions to transform associated reference scenarios). The ensemble mean of three regional climate models (RCM), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO), has been used for the analysis. The ensemble mean is chosen to reduce model-related uncertainties, and the ensemble mean climate is closer to the observed climate than in any individual model.

[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
[26] 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.

- **PRECIPITATION PROJECTIONS**

The following is a summary of the projected change in precipitation in the Pong basin in the IPCC AR5 RCP4.5 and RCP8.5 scenarios:

- The average annual rainfall in the IPCC AR5 RCP4.5 scenario is projected to increase by 5.6% towards mid-century and increase by about 11.8% towards end-century, while in the IPCC AR5 RCP8.5 scenario it is projected to increase by about 13% towards mid-century and by 11.7% towards end-century for the basin (Table 30).
- Districts in the very high hills temperate dry zone of the Pong basin in the south show the highest projected increase in annual rainfall relative to the other districts of the Pong basin towards EC with respect to BL for the IPCC AR5 RCP4.5 scenario. Kullu district, in the high hills temperate wet zone, shows the lowest projected increase towards both MC and EC (Figure 49).
- Districts in the very high hills temperate dry zone of the Pong basin district show the highest projected increase in annual rainfall (about 28%) towards EC with respect to BL for the IPCC AR5 RCP8.5 scenario. Kullu and Chamba districts show the lowest projected increases towards both MC and EC (Figure 51).
- The monsoon (June, July, August and September) rainfall contributes most to the annual rainfall in the Pong basin (approximately 57%), followed by that of the post-monsoon season (about 18%). The contribution of the winter and pre-monsoon seasons together is about 25% (Table 30).
- In the monsoon (JJAS) and the post-monsoon season (OND), a rainfall increase is projected, while in winter (JF) and the pre-monsoon season (MAM), a rainfall decrease is projected towards MC and EC as compared with BL for the Pong basin in the IPCC AR5 RCP 4.5 and RCP 8.5 scenarios.

***Table 30** Change in precipitation (%) with respect to baseline (1981–2010) for Pong basin (RCP 8.5)*

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
Basin/District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Pong Basin	**13.3**	**11.7**	**-21.6**	**-30.5**	**-1.1**	**-20.7**	**19.3**	**27.6**	**28.1**	**12.5**
Chamba	11.2	10.0	-21.0	-34.2	-0.7	-21.4	15.9	33.9	30.3	4.4
Hamirpur	14.5	13.1	-39.8	-42.4	-16.0	-36.6	19.7	21.7	24.6	11.6
Kangra	13.2	12.2	-30.8	-42.6	-8.2	-32.9	19.4	30.1	29.7	3.3
Kullu	13.0	9.0	-11.7	-20.6	1.9	-19.0	20.2	30.0	28.3	17.3
Mandi	14.3	12.6	-29.3	-35.9	-10.0	-37.5	18.8	20.3	27.3	21.8
Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean										

Photo credit: CarrotFilms.GIZ

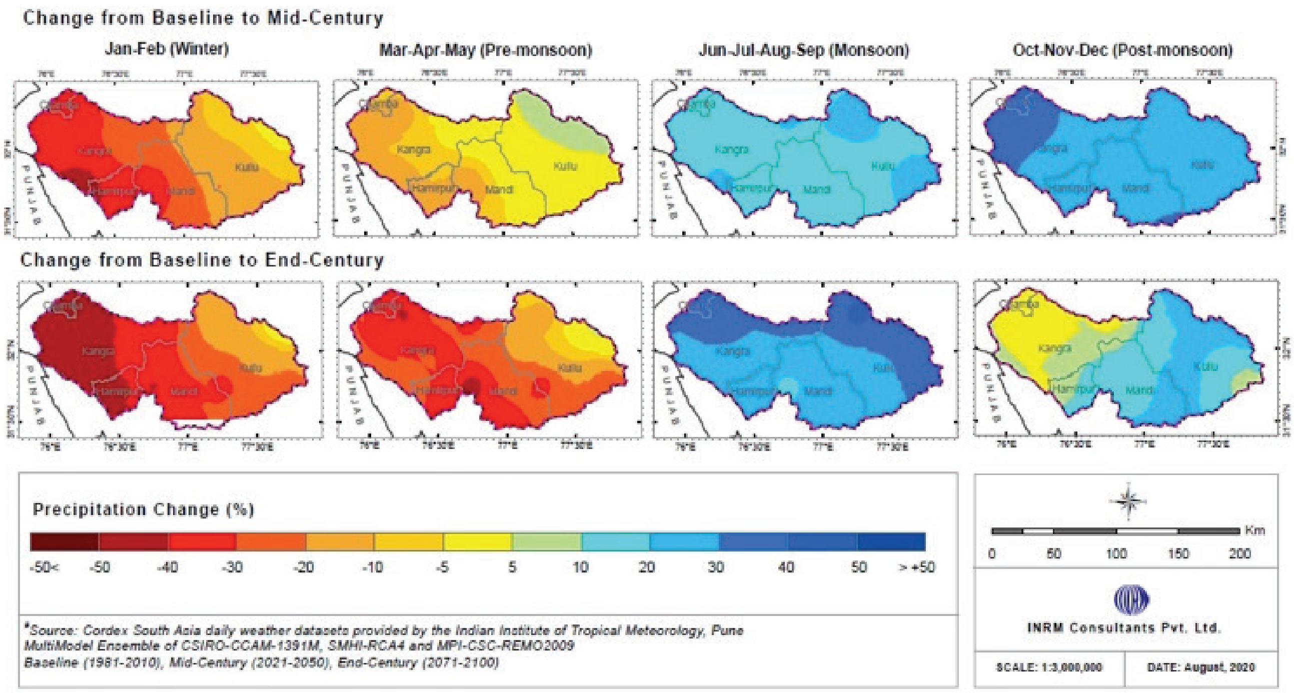


Figure 51 *Projections of changes in seasonal precipitation for MC and EC with respect to the 1981–2010 baseline for the Pong basin (RCP 8.5)*

TEMPERATURE PROJECTIONS

The following is a summary of the projected change in temperature in the IPCC AR5 RCP 4.5 and RCP 8.5 scenarios:

- The average annual maximum temperature in the IPCC AR5 RCP 8.5 scenario is projected to increase by about 1.8°C towards mid-century and 5.3°C towards end-century for the Pong basin (Table 31).
- The average annual minimum temperature in the IPCC AR5 RCP 8.5 scenario is projected to increase by about 1.8°C towards mid-century and 5.0°C towards end-century in the Pong basin.
- The highest maximum temperature increase is projected in winter in the IPCC AR5 RCP 4.5 and RCP 8.5 scenarios towards MC and EC in the Pong basin compared with the other seasons (Table 31, Figure 52).
- The highest minimum temperature increase is projected in the monsoon in the IPCC AR5 RCP 4.5 scenario and RCP 8.5 scenario for both MC and EC in the Pong basin compared with the other seasons.
- The projected increase in maximum temperature towards MC varies from 1.5°C in Hamirpur to 1.9°C in Kullu district, of the Pong basin, in the IPCC AR5 RCP 8.5 scenario. The projected increase in the maximum temperature towards EC varies from 4.6°C in Hamirpur to 5.7°C in Chamba district in the IPCC AR5 RCP 8.5 scenario.
- In both the IPCC AR5 RCP 4.5 and RCP 8.5 scenarios, an increase in the annual and seasonal minimum temperature is projected in the Pong basin and districts falling in it towards MC and EC. However, the increase in the IPCC AR5 RCP 8.5 scenario is much higher than that of the IPCC AR5 RCP 4.5 scenario.

Table 30 *Change in daily maximum temperature (°C) with reference to a 1981–2010 baseline in the Pong basin (RCP8.5)*

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
Basin/District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Pong Basin	**1.8**	**5.3**	**2.3**	**5.8**	**1.8**	**5.4**	**1.9**	**5.8**	**1.2**	**4.4**
Chamba	1.8	5.7	2.4	6.2	1.7	5.4	2.1	6.6	1.4	4.8
Hamirpur	1.5	4.6	2.1	5.3	2.0	5.6	1.1	4.1	0.9	3.7
Kangra	1.7	5.2	2.2	5.7	2.0	5.6	1.6	5.3	1.1	4.3
Kullu	1.9	5.5	2.3	5.9	1.7	5.3	2.2	6.2	1.2	4.5
Mandi	1.7	5.2	2.4	5.7	1.9	5.5	1.6	5.4	1.1	4.0
Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean										

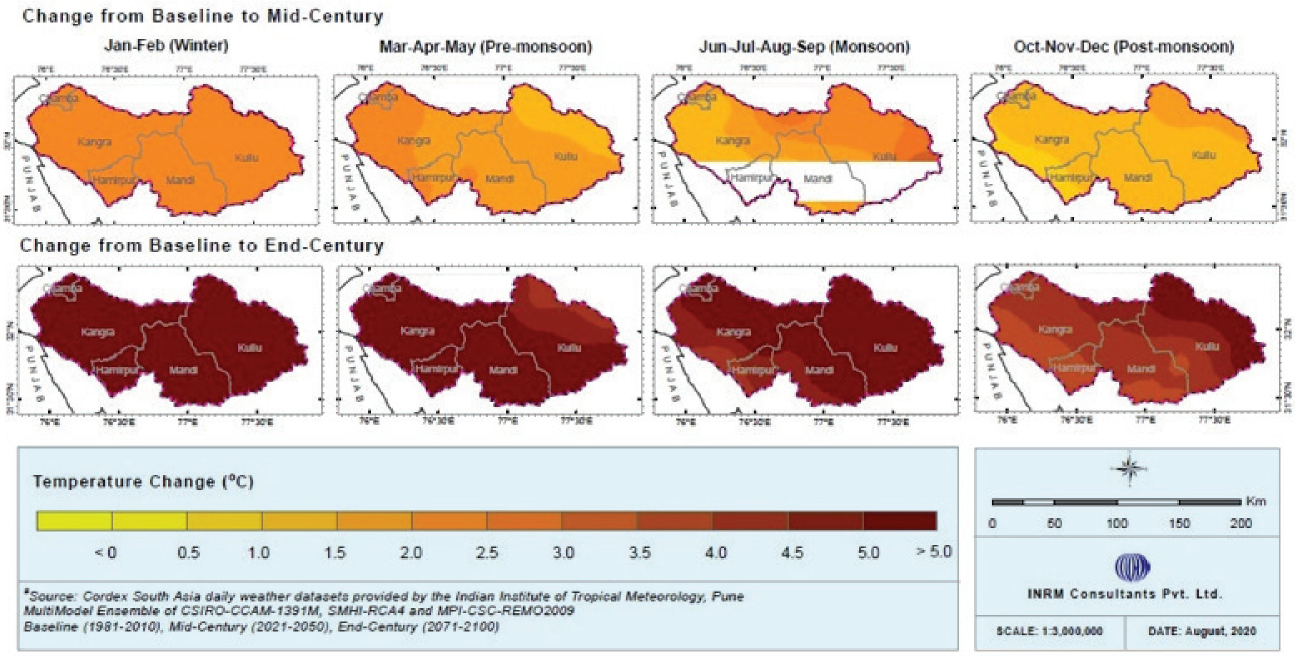


Figure 50 *Projections of changes in seasonal maximum temperature for MC and EC with respect to baseline (1981–2010) in the Pong Basin (RCP 8.5)*

ANNEX 3 – LIST OF VULNERABILITY ASSESSMENT MATRICES

The matrices are attached as complementary material.

Table 32 *Vulnerability Assessment Matrices*

Target asset	Attached file
Pong Dam Hydel project	AAS2010-REP-003-02 Final Report PongDam (Annex 3.1 VA_Pong Hydel).docx
Catchment area	AAS2010-REP-003-02 Final Report PongDam (Annex 3.2 VA_Catchment).docx
Pong Reservoir	AAS2010-REP-003-02 Final Report PongDam (Annex 3.3 VA_Pong Reservoir).docx
Bar-headed Goose (BHG) and Northern Pintail (NP)	AAS2010-REP-003-02 Final Report PongDam (Annex 3.4 VA_BHG&NP).docx
Golden Mahseer *(Tor putitora)*	AAS2010-REP-003-02 Final Report PongDam (Annex 3.5 VA_Golden Mahseer).docx
Migratory birds	AAS2010-REP-003-02 Final Report PongDam (Annex 3.6 VA_ Migratory Bird Habitats).docx
Fisheries	AAS2010-REP-003-02 Final Report PongDam (Annex 3.7 VA_Fisheries).docx

ANNEX 3 – LIST OF VULNERABILITY ASSESSMENT MATRICES

Annex 3.1 - Vulnerability Assessment Matrix for the Pong Dam Hydel

ASSET NAME: PONG DAM HYDEL

ASSET DESCRIPTION: Pong dam stored water is primarily used for meeting irrigation water demands for which a total of 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.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	High[1]	Low[2]	Medium	**Direct impacts:** • Increased erosion in the catchment leads to increased sediment loads in the reservoir, smothering of aquatic plant habitat and shift of mudflat zones. • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp. • Due to the increase in rainfall by 5% in the Pong catchment, there shall be an increase of 9.7% in surface runoff in mid-century in RCP 4.5 scenario in Pong catchment whereas, by the end-century with an 11% increase in rainfal (RCP 4.5 scenario), the surface runoff shall increase by 12%3. **Indirect impacts:** • Human Populations may need resettlement and rehabilitation. • Increased potential for power generation and downstream irrigation • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	High[4]	Medium

[1]Pong dam serves the purposes of storing water for irrigation, power generation and flood control. This has is open reservoir and have huge area. Spillways and gates will play an important role.

[2]Water levels are maintained by the dam operation, so sensitivity is low. Maybe a reduced habitat zone because the reservoir is filled quicker and more frequently during the wet season.

[3]NRM 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.

[4]This hydel dam is designed to serve storing water for irrigation, power generation and flood control. Therefore, increased rainfall will not affect the working of dam as well as the catchment area.

<table>
<tr><th rowspan="2">Threat category</th><th rowspan="2">Details of threat</th><th>Exposure</th><th>Sensitivity</th><th>Impact level</th><th>Impact summary</th><th rowspan="2">Adaptive capacity</th><th rowspan="2">Vulnerability</th></tr>
<tr></tr>
<tr><td colspan="8">PRECIPITATION</td></tr>
<tr><td>Decrease of rainfall during Winter (Jan-Feb) and pre-monsoon season (Mar-May)</td><td>Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the catchment. Also a slight decrease in rainfall during Pre-Monsoon (5.3%).</td><td>High[5]</td><td>Medium[6]</td><td>High</td><td>Direct impacts:
• Reservoir level low and water availability will be less for hydropower generation and irrigation.
• Arable winter crops grown around the reservoir may be less productive.
Indirect impacts:
• Fish production is dependent upon water level and area, so may decrease more rapidly.
• Migratory bird habitats may be slightly less attractive.</td><td>Low[7]</td><td>High</td></tr>
<tr><td colspan="8">TEMPERATURE</td></tr>
<tr><td>Increase of temperature during the hot season/ Monsoon (Jun-Sep)</td><td>An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.</td><td>Very High[8]</td><td>High[9]</td><td>Very High</td><td>Direct impacts:
• Snow and glacier melt runoff in Beas catchment were studied for the years 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).
• Average annual maximum temperature for IPCC AR 5 RCP 4.5 scenario is projected to increase by about 1.5°C towards mid-century and by 2.8°C towards end-century while for IPCC AR5 RCP 8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.3°C towards end-century for Pong Basin State.3</td><td>Low[10]</td><td>Very High</td></tr>
</table>

[5]Decrease of 50 mm during the dry season may be important for these areas, especially when combined with increased temperatures, which will increase evapotranspiration and push the climate towards greater seasonal aridity. Decreased rainfall and increased temperatures in the dry season will increase demand for irrigation water releases, resulting in a more rapid drawdown area.

[6]The reservoir level will be beginning to fall, therefore area is used to adapted to drawing down but there may be increased demand for irrigation water.

[7]Since dams are designed for certain live storage and hydraulic head. Reservoir water levels will be low and are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation.

[8]Marked increase in max and average temperatures will increase the evaporation from the reservoir surface.

[9]Marked increase in max and average temperatures will adversely affect the working of hydel structure including hydraulic machines such as turbines.

[10]No possibility of natural adaptation to this range of high temperatures. Possible to reduce water temp through sheltering (e.g. floating solar) or through planting of riparian trees, and improving water quality through mechanical water aeration in the reservoir, but expensive.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					• Average annual minimum temperature for IPCC AR5 RCP 4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.7°C towards end-century while for IPCC AR5 RCP 8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.0°C towards end-century for Pong Basin State. Thus projected temperature increase towards EC is higher than that of MC. • Due to the high daily difference in temperature between the surface and near-surface areas of the dam, surface cracks may be developed. Cracks adversely affect water tightness, durability and therefore, are undesirable. • Surface water temperature increases will enhance evaporation losses and the working of hydraulic machines. • Surface water temperature increases during summer, possibly beyond threshold limits for vegetation and some aquatic species. • Crops above the reservoir tend not to grow so well unless irrigated. **Indirect impacts:** • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water • Need to change the choice of crops to those more suited to higher temperatures		

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the cold season (Oct-May)	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from 23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.	High[11]	High[12]	High	**Direct impacts:** • Increase in evapotranspiration and less power generation. **Indirect impacts:** • Hydraulic machines may need cooling at high-temperature conditions and therefore, finances may be required.	Low[13]	High
EXTREME EVENTS							
Flood/ Flash flood	Increase in frequency and magnitude of flooding during monsoon season	High[14]	Medium[15]	High	**Direct impacts:** • Will help in filling the reservoir and increase power generation and irrigation. • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding. • One day maximum rainfall events shall increase in RCP 4.5 and RCP 8.5 scenario resulting in more flood like events in future. **Indirect impacts:** • Increase in sediment in the reservoir from increased erosion • Water quality will be affected because of high nutrient load. • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	High[16]	Medium

11 More warm days in the dry season will increase evapotranspiration and push the climate towards greater seasonal aridity. Increased temperatures in the dry season will increase demand for irrigation water releases, resulting in a more rapid drawdown.

12 More warm days will enhance increase in evapotranspiration and will lead to less power generation.

13 Management capacity is low to address these changes.

14 Pong Dam serves the purposes of storing water for irrigation, power generation and flood control.

15 Dams are designed to control floods. Water levels are regulated & can be managed by HPP.

16 Reservoir water levels are regulated and can be managed by HPP in case of flood.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Drought	Increasing consecutive days of drought	**Medium**[17]	**Low**[18]	**Medium**	**Indirect impacts:** • Irrigation will get affected. • Vegetation will also get affected. • The low water level in the reservoir and Low soil moisture **Indirect impacts:** • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants	**Medium**[19]	**Medium**
Wind	Increase in high wind events and wind speed in autumn and winter	**Low**[20]	**Low**[21]	**Low**	**Direct impacts:** • High water waves will lead to an increase in the exposure of water surface, so increase evapotranspiration. • May affect hydraulic machines and gates. **Indirect impacts:** • High winds and large waves will reduce the life of hydraulic machines. • Erosion of shoreline on the north-eastern shore • Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills	**High**[22]	**Low**

[17]Minimum water storage requirement is maintained by HPP and therefore exposure will be medium.

[18]Since minimum water level is being maintained for day to day operation i.e. hydropower generation and irrigation will not have much effect. Therefore, sensitivity will be low. However, irrigation may suffer from the lack of water.

[19]Overall Natural Adaptive capacity will be medium because Reservoir water levels are regulated and can be managed by HPP in case of drought.

[20]The functioning of the Pong dam hydel structure will have insignificant impact due to the the wind. High water waves may be (1) increasing exposure of water surface, so increase evapotranspiration (2) may affect hydraulic machines and gates.

[21]Hydraulic machines and gates may experience higher wind load if there is high speed wind. Though these structures are designed while considering wind loads.

[22]Hydel dam is designed while considering the wind speed.

Annex 2.1.1 – Scoring matrices

		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	High
	Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

		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 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*

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					• Snow and glacier melt runoff in Beas catchment were studied for the years 1990 to 2004 by Kumar et al. (2007) and its contribution is about 35 % of the annual flow at Pong Dam (upstream of Pong dam). **Indirect impacts:** • Due to the high daily difference in temperature between the surface and near-surface areas of the dam, surface cracks may be developed. Cracks adversely affect water tightness, durability and therefore, are undesirable. • Surface water temperature increases will enhance evaporation losses. • Surface water temperature increases during summer, possibly beyond threshold limits for vegetation and some aquatic species. • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water • Need to change the choice of crops to those more suited to higher temperatures		
Increase of temperature during the cold season (Oct-May	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from	**Medium**[10]	**Medium**[11]	**Medium**	**Direct impacts:** • Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants • Increase temperature will lead to higher evapotranspiration and high-water withdrawals will greatly undermine the fish species diversity and distribution in the Pong dam.	**Low**[12]	**Medium**

[10]The changes in temperature are not significant. However, more warm days during the dry season will increase evapotranspiration and push the climate towards greater seasonal aridity. Increased temperatures in the dry season will increase demand for irrigation water releases, resulting in a more rapid drawdown.
[11]The changes in temperature are not significant. However, more warm days will increase evapotranspiration and will lead to less power generation.
[12]Current management capacity is low to address these changes.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
	23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.				• Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species • A significant increase in evaporation losses will affect reservoir operations **Indirect impacts:** • Reduced migration of these birds due to increased winter temperatures • Hydraulic machines may need cooling at high-temperature conditions and therefore,		
EXTREME EVENTS							
Flood/ Flash flood	Increase in frequency and magnitude of flooding during monsoon season	**High**[13]	**Medium**[14]	**High**	**Direct impacts:** • Flood like events in the future shall cause more erosion in the area. This erosion shall result in additional sedimentation in the future. • Turbidity shall be highest in the monsoon and post-monsoon season in the catchment. • Reduced capacity of the reservoir shall increase the flood risk. • Increase in sediment in the eservoir from increased erosion **Indirect impacts:** • Will help in filling the reservoir and increase power generation and irrigation. • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding.	**High**[15]	**Medium**

[13]Frequent flooding in the past years poses as a serious threat for wetland ecology, biodiversity of the region and human settlements downstream of the dam.

[14]Pong reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The total length of the reservoir is 41.8 km with the widest stretch of 19.0 km. Dams are designed to control floods. Water levels are regulated and can be managed by HPP.

[15]Heavy rainfall in the monsoon season results in erosion, flood and landslides, which in turn results in lot of lose soil and debris flowing down the river and getting collected in the reservoir. These hotspot areas are more prone to sedimentation. This hydel dam is designed to serve storing water for irrigation, power generation and flood control. Reservoir water levels are regulated and can be managed by HPP in case of flood.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Water quality will affect because of nutrient load. • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants		
Drought	Increasing consecutive days of drought	**Medium**[16]	**Low**[17]	**Medium**	**Direct impacts:** • The drought condition will affect the recharge of groundwater and over time reducing the aquifer level below access by boreholes • Irrigation in the upper catchment will get affected, due to a decline in groundwater and soil moisture in the catchment • Vegetation will also get affected due to low soil moisture in drought conditions. • Increasing fire risks within the catchment. • Increased demand for irrigation water from the reservoir. **Indirect impacts:** • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants • Lower water levels in the reservoir and lower soil moisture • Potential for algal blooms and reduce water quality	**Medium**[18]	**Medium**

[16]Landuse study of the area suggests that the agriculture area has increased by 16.7% during the last 20 years. Barren land has decreased between the years 2001 and 2020 by 16.4%. Minimum water storage requirement is maintained by HPP and therefore exposure will be medium.

[17]These land conversions to agricultural lands might increase rate of sedimentation in the wetland, which in turn can affect hydropower production and the reservoir storage capacity. Apart from sedimentation issue, increase in agriculture land might affect the water quality of the wetland. This rate is likely to increase in the near future due to large scale of urbanization and development in the area especially at major tourist places. However, the minimum water level in catchment is being maintained for day to day operation i.e. hydropower generation and irrigation will not bemuch affected. Therefore, the sensitivity will be low.

[18]Overall Natural Adaptive capacity will be medium because reservoir water levels are regulated and can be managed by HPP in case of drought.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Wind	Increase in high wind events and wind speed in autumn and winter	**Low**[19]	**Low**[20]	**Low**	**Indirect impacts:** • The wind impacts are around the reservoir not for the whole catchment. **Indirect impacts:** • High water waves will lead to an increase in the exposure of water surface, so increase evapotranspiration. • May affect hydraulic machines and gates. • High winds and large waves will reduce the life of hydraulic machines. • Erosion of shoreline on the north-eastern shore. • Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills.	**High**[21]	**Low**

[19]Pong reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The total length of reservoir is 41.8 km with the widest stretch of 19.0 km. The functioning of the catchment will have insignificant impacts due to the wind.
[20]Pong reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The total length of reservoir is 41.8 km with the widest stretch of 19.0 km. The functioning of catchment will have insignificant impacts due to the wind.
[21]A catchment area of 12,561 km^2, out of which the area with permanent snow catchment is 780 km^2.

Photo credit: CarrotFilms.GIZ

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 3.3 - Vulnerability Assessment Matrix for the Pong Reservoir

ASSET NAME: RESERVOIR

ASSET DESCRIPTION: Open deep water, Shallow water in the drawdown, Dry sandbanks with little or no vegetation, Waterside vegetation and swamps below the out-fall from the dam.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	**Very High[1]**	**High[2]**	**Very High**	**Direct impacts:** • Increased areal water extent will lead to disturbances in the ecosystem through changes in water quality, turbidity, dissolved oxygen, surface water temperature and depth profiles of the aerobic layer. • Increased erosion in the catchment leads to increased sediment loads in the reservoir. • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in Terrace swamp. **Indirect impacts:** • Increased potential for power generation and downstream irrigation (+ve). • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	**Medium[3]**	**Very High**

[1]Note that wet season rainfall increase will lead to change in the water extent, which can significantly affect water quality, turbidity and dissolved oxygen.

[2]Sediment in the reservoir projected to increase from 23 to 26 MmT/year, 75% of which settle in live zone, sedimentation from the increased erosion will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones. Moreover, the water extent of reservoir influences various water quality parameters. Maybe a reduced habitat zones because the reservoir is filled quicker and more frequently during the wet season, so the sensitivity is high.

[3]Adaptive capacity can be directly relating to management capacity. Pong reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The total length of reservoir is 41.8 km with the widest stretch of 19.0 km. Therefore, the increased rainfall will not affect the working catchment area. With increased rainfall and sediment, HPP dam can adapt by managing the flows and release of water in the reservoir.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during Winter (Jan-Feb) and pre- monsoon season (Mar-May)	Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the catchment. Also a slight decrease in rainfall during pre-monsoon (5.3%).	High[4]	Medium[5]	High	**Direct impacts:** • Drawn down exposes sandbanks, which can be potential nesting sites. • Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out **Indirect impacts:** • Shallow water area available for bird feeding will be reduced or extend further into the reservoir • Fish production is dependent upon water level and area, so may decrease more rapidly	Medium[6]	High
TEMPERATURE							
Increase of temperature during the hot season /Monsoon (Jun-Sep)	An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.	Very High[7]	High[8]	Very High	**Direct impacts:** • Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species • Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l. • Riparian and aquatic vegetation flourishes • Significant increase in evaporation losses **Indirect impacts:** • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water	Low[9]	Very High

[4]Decrease of 50 mm during the dry season may be important for these areas, especially when combined with increased temperatures, which will increase evapotranspiration and push the climate towards greater seasonal aridity. Decreased rainfall and increased temperatures in the dry season will increase the demand of irrigation water releases, resulting in a more rapid drawdown

[5]The reservoir level will be beginning to desrease, exposing the shallow mudflat zone. The habitat would be progressively the drawndown, but only fully exposed at end of the dry season. Area is used to adapted to drawing down but there may be an increase in the demand of irrigation water. Therefore, the sensitivity is medium.

[6]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation

[7]Marked increase in temperature will increase evaporation losses and affect reservoir operations.

[8]Shallow water habitats around the reservoir will heat up and are often already very high (surface water temp recorded up to 40oC). Dissolved O2 conc. is already showing a downward trend. Aquatic vegetation and phytoplankton may be enhanced, but riparian and terrestrial vegetation and crops will increase evapotranspiration and may not grow so well. Evaporation from the reservoir surface will be increased.

[9]The reservoir will be exposed to higher temperatures and no possibility of natural adaptation. It is possible to reduce water temp through sheltering (e.g. floating solar) or through planting of riparian trees, and improving water quality through mechanical water aeration in the reservoir, but it will be expensive.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the cold season (Oct-May)	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from 23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.	Medium[10]	Medium[11]	Medium	**Direct impacts:** • A significant increase in evaporation losses will affect reservoir operations • Continued plant and phytoplankton growth and zooplankton through winter • Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants	Low[12]	Medium
EXTREME EVENTS							
Flood	Increase in frequency and magnitude of flooding during monsoon season	High[13]	Medium[14]	High	**Direct impacts:** • Flood should not have significant impacts on the reservoir as it is an inundated area and the water level is regulated. • Areal water extent increase at an intense rate led to disturbances and others. • Increase in sediment in the reservoir by erosion • Decrease in D.O and water quality due to organic matter and sediment run-off in floodwater. **Indirect impacts:** • Increased potential for power generation and downstream irrigation.	Medium[15]	High

[10]Fewer frosts, more warm days.
[11]Will allow more temperature sensitive plants to survive, may bring on crops and plants in spring time and at end of the dry season so that they start growing earlier.
[12]Natural adaptive capacity includes shifts in plant species or reduced need for migration, the management capacity is low to address these changes.
[13]Changes in wetland characteristics affecting ecosystem such as water quality, turbidity, dissolved oxygen, surface water temperature and depth profiles of aerobic layer. Submergence of breeding sites of migratory birds and aquatic plant habitat and shift of mudflat zones.
[14]Flooding will bring more sediment in the reservoir from the increased erosion and will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones, so the sensitivity is medium. Maybe a reduced habitat zones. However, water levels are regulated and can be managed by HPP.
[15]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Regulation of water from reservoir increased, which may increase the frequency of downstream flooding in Terrace swamp.		
Flash flooding	Occurs during monsoon – mid-July to mid-August not later in the wet season	**Low[16]**	**Low[17]**	**Low**	**Direct Impacts** • Sediment smothering in upper areas of the reservoir. • Flash flooding is likely to increase with an increase in sediment beyond modelled, as catchment degrades immensely. • Significant Downstream impacts of flooding.	**High[18]**	**Low**
Flash flooding	Occurs during monsoon – mid-July to mid-August not later in the wet season	**High[19]**	**High[20]**	**High**	**Direct impacts:** • Increased demand for irrigation water from the reservoir. • A lower water level in the reservoir. • Potential for algal blooms and reduce water quality **Indirect impacts:** • Reduced potential for power generation • Reduced bio-mass and aquatic plants. • Potential drying of downstream swamp areas. • Potential reduction in fish populations and catches.	**Medium[21]**	**High**

[16]Flash flooding is limited to some small areas within the reservoir. The volume of water is relatively small and would not effect the large reservoir.

[17]The size of the reservoir can absorb flash flood and water levels in reservoir can absorb any flooding as these can be regulated by flow regulation by dam authorities.

[18]Flows regulated by dam authorities (so adaptive capacity is high). Study regarding flash flood with erosion/sedimentation may be required.

[19]Shallow water in the drawdown during drought seasons, especially March-June. If there is a drought during Oct-March, habitat & breeding sites will be affected due to low water levels. Therefore, the exposure will be high.

[20]Reservoir will be exposed to higher temperatures and deficit precipitation and no possibility of adaptation to it through reservoir operations. During drought seasons especially March-June. If there is a drought during Oct-March, habitat & breeding sites will be affected due to low water levels. Therefore, the sensitivity will be high.

[21]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Wind	Increase in high wind events and wind speed in autumn and winter	**High**[22]	**Medium**[23]	**High**	**Direct impacts:** • Erosion of shoreline on the northeastern shore • Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills **Indirect impacts:** • High winds and large waves will make boating more challenging for fishing activities and reduce tourist attraction at some times of day.	**Medium**[24]	**High**

[22]The wind in the area of the Pong reservoir is of utmost importance in the forenoon of the winter season the wind movements are generally from east to the western side and in the afternoon, its movements have been observed from the western to the east northern direction.
[23]The Pong reservoir being the huge water body experiences the rising waves depending upon the wind velocity. Sometimes, wind velocity goes up to 100 nautical miles per hour.
[24]Pong reservoir has a maximum depth of 97.84 m and a mean depth of 35.7 m. The total length of reservoir is 41.8 km with the widest stretch of 19.0 km. The adaptive capacity is high.

Photo credit: CarrotFilms.GIZ

Annex 3.3.1 – Scoring matrices

	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	High
Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

	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 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 3.4 - Vulnerability Assessment Matrix for Bar-headed Geese and Northern Pintail

ASSET NAME: BAR-HEADED GEESE AND NORTHERN PINTAIL

ASSET DESCRIPTION: Bar-headed Geese (> 45% world's population) and Northern Pintail are seen in the large congregations in this wetland. Bar-headed Geese are herbivores (graminivores, granivores) and feed mainly on grasses that surround lakes where they nest. They also eat corn, barley, rice, wheat, and occasionally will take mollusks, insects, and crustaceans. In 2020, the total count of these birds at the lake was 29,443 while in 2021, 49,496 Bar-headed Geese have visited the lake. Bar-headed Geese breed in high-altitude wetlands that are up at 4,000 to 5,000 meters.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	Very High[1]	Medium[2]	Very High	**Direct impacts:** • Since these birds are not present during the Monsoon, there will be no direct impacts on their populations. • Increased sedimentation in the reservoir due to augmented erosion would smother aquatic habitat and shift of mudflat zones. • Downstream flooding due to frequent water releases from the reservoir can affect the D/S wetland habitat of these birds. **Indirect impacts:** • Habitat changes may affect food availability during their residency. • Increased reservoir filling and area will enhance fish productivity and enrich the habitats of these birds. • Populations of these migratory birds dependent upon aquatic plants may sustain reduced populations, e.g. teal • Geese and lapwings could benefit from increased arable production feed • Increased potential for power generation and downstream irrigation	Medium[3]	Very High

[1]Due to the high-water level, the bar-headed geese and northern pintail do not have open spaces to stay put.

[2]These areas are seasonally flooded by the reservoir, and water levels are maintained by the dam operation. Sediment in the reservoir projected to increase from 23 to 26 MmT/year, 75% of which settle in live zone. Sedimentation from the increased erosion will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones. Maybe a reduced habitat zones because the reservoir is filled quicker and more frequently during the wet season. Therefore, sensitivity is medium

[3]Adaptive capacity may be direct relating to natural habitat capacity of ecosystems and species or indirect relating to the management capacity. This a balance between the natural capacity of the wetland to adapt to increased rainfall and sediment, and the management capacity of the HPP dam to manage the flows and release of water in the reservoir.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during Winter (Jan-Feb) and pre- monsoon season (Mar-May)	Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the catchment. Also a slight decrease in rainfall during pre-monsoon (5.3%).	High[4]	Medium[5]	High	**Direct impacts:** • Drawn down exposes sandbanks, which can be potential nesting sites. • Slightly less attractive habitats for these migratory birds. • Shallow water area available for bird feeding will be reduced or extend further into the reservoir • Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out **Indirect impacts:** • Water level variation impact fish production so may decrease more rapidly. • Less productive arable winter crops (rainfed) around the reservoir.	Medium[6]	High
TEMPERATURE							
Increase of temperature during the hot season/ Monsoon (Jun-Sep)	An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.	Very High[7]	High[8]	Very High	**Direct impacts:** • Since these birds are not present during the Monsoon, there will be no direct impact on their populations. • During summer, surface water temperature increases, possibly beyond threshold limits for some aquatic species • With the increase in temperature, dissolved oxygen in water decreases even below the threshold levels of 5 mg/l • Increasing phytoplankton and associated zooplankton growth and algal blooms, possibly increasing blue-green algae • Crops above reservoir tend not to grow so well unless irrigated	Low[9]	Very High

[4]Decrease of 50 mm during the dry season may be important for these areas, especially when combined with increased temperatures, which will increase evapotranspiration and push the climate towards greater seasonal aridity. Decreased rainfall and increased temperatures in the dry season will increase the demand for irrigation water releases, resulting in a more rapid drawdown

[5]The migratory birds (bar headed geese and northern pintail) arrive during September/October and depart during February/March. The reservoir level will be beginning to decrease, exposing the shallow mudflat zones. The habitat would be progressively drawn down, but only fully exposed at end of the dry season. Area is used to adapted to drawing down but there may be an increase in the demand of irrigation water.

[6]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation.

[7]A marked increase in max and average temperatures will shift the bioclimate zone of Pong Dam from Hot and mesic, towards extremely hot and arid, which can significantly affect the population of migratory birds, especially bar headed geese and northern pintail.

[8]Shallow water habitats around the reservoir will heat up. Dissolved O2 conc. is already showing a downward trend. Aquatic vegetation and phytoplankton may be enhanced, but riparian and terrestrial vegetation and crops will increase evapotranspiration and may not grow so well.

[9]No possibility of natural adaptation to this range of high temps. It is possible to reduce water temp through sheltering (e.g. floating solar) or through planting of riparian trees, and improving water quality through mechanical water aeration in the reservoir, but it will be expensive.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					Indirect impacts: • Habitat changes may affec food availability during their residency. • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water • Change in cropping pattern to those more suited to higher temperatures		
Increase of temperature during the cold season (Oct-May)	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from 23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.	High[10]	High[11]	High	**Direct impacts:** • Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants • Reduced migration of these birds due to increased winter temperatures **Indirect impacts:** • Continued plant and phytoplankton growth and zooplankton through winter	Low[12]	High
EXTREME EVENTS							
Flood	Increase in frequency and magnitude of flooding during monsoon season	High[13]	High[14]	High	**Direct impacts:** • Since these birds are present during the Monsoon, there will be no direct impacts on their populations.	Medium[15]	High

[10]Fewer frosts, more warm days.

[11]Will allow more temperature sensitive plants to survive, may bring on crops and plants in spring time and at end of the dry season so that they start growing earlier. This is the season for migratory birds, will they feel too hot or stay in their breeding areas?

[12]Natural adaptive capacity includes shifts in plant species or reduced need for migration, management capacity is low to address these changes.

[13]Submergence of breeding sites of migratory birds (bar headed geese and northern pintail) and aquatic plant habitat and shift of mudflat zones.

[14]Flooding will bring more sediment in the reservoir from the increased erosion and will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones, so the sensitivity is high. Maybe a reduced habitat zones. However, water levels are regulated & can be managed by HPP.

[15]Reservoir water levels are regulated and can be managed by HPP in case of flood. The adaptive capacity may be direct relating to the natural habitat capacity of ecosystems and species or indirect relating to the management capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Shifts of mudflat zones • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in Terrace swamp. • Increased reservoir filling and area will enhance fish productivity **Indirect impacts:** • Habitat changes may affect food availability during their residency. • Flood will lead to closing to sites • Water quality will affect due to nutrient load. • Increased potential for power generation and downstream irrigation • Increased sedimentation of the reservoir due to increased erosion		
Flash flooding	Occurs during monsoon – mid-July to mid-August not later in the wet season	Low[16]	Low[17]	Low	**Direct Impacts** • Since these birds are present during the Monsoon, there will be no direct impacts on their populations. • Increased degradation of the catchment, will lead to flash flooding, possible increase in sediment beyond modelled. • Sediment smothering of upper areas of the reservoir but the trends in past 10 years show little to change in these areas. **Indirect impacts** • Habitat changes may affect food availability during their residency. • Downstream impacts flooding can be very significant	High[18]	Low

[16]The Exposure is low because migratory birds will not be present during the flooding seasons. The expanse of habitat area is so large that even flash flooding will be absorbed.

[17]Because migratory birds will not be present during the flooding seasons. The expanse of habitat area is so large that even flash flooding will be absorbed. Water levels in reservoir can absorb any flooding that may happen.

[18]Natural Adaptive capacity quite high because the absence of migratory birds during this time. Study regarding flash flood with erosion/sedimentation may be required.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Drought	Increasing consecutive days of drought	**Low[19]**	**Low[20]**	**Low**	**Direct impacts:** • Low water levels in the reservoir and Low soil moisture affect crops and can affect the food supply for migratory birds • Vegetation and crops will get affected, affecting the food supply for these birds. **Indirect impacts:** • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants	**Medium[21]**	**Medium**
Wind	Increase in high wind events and wind speed in autumn and winter	**High[22]**	**Medium[23]**	**High**	**Direct impacts:** • Disturbance of migratory birds especially on northeastern shore in afternoons – may cause shifts of birds to more sheltered bays • Erosion of shoreline on the northeastern shore **Indirect impacts:** • Intense intermixing of reservoir waters might lead to inversion of anaerobic layers, leading to fish kills	**Medium[24]**	**High**

[19]Migratory birds will not be present during the drought seasons especially March-June. If there is a drought during Oct-March, habitat & breeding sites will be affected due to low water levels. Therefore, the exposure will be low.

[20]Migratory birds will not be present during the drought seasons especially March-June. If there is a drought during Oct-March, habitat & breeding sites will be affected due to low water levels. Therefore, the sensitivity will be low.

[21]Overall Natural Adaptive capacity will be medium because (1) the absence of migratory birds (bar headed geese and northern pintail) during March- Sept if there is a drought -High (2) If there is a drought during Oct- March and migratory birds are there, then – low. This results in an overall Adaptive capacity of Medium.

[22]Autumn starts from mid-September to mid-December, when migratory birds arrive. The frost and wind are common during this period. The wind in the area of the Pong reservoir is of utmost importance in the forenoon of the winter season the wind movements are generally from the east to the western side and in the afternoon, its movements have been observed from the western to the east northern direction. The Pong reservoir being the huge water body experiences the rising waves depending upon the wind velocity. Sometimes, the wind velocity goes up to 100 nautical miles per hour.

[23]Aquatic plants, trees may get damaged if there is high speed wind and a number of wind events.

[24]Little that can be done naturally or management except for providing safer fishing and boating craft.

Annex 3.4.1 – 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 3.5 - 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, Pong Dam.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	High[1]	Medium[2]	High	**Direct impacts:** • During increased rainfall in the monsoon season because of high water turbidity in the Himalayan rivers and Pong Dam that provides a protective cover to fish and reduces the risk of being attacked by visual predators. • Increased reservoir filling and area will enhance fish productivity.	Medium[3]	High
Decrease of rainfall during Winter (Jan-Feb) and pre- monsoon season (Mar-May)	Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the catchment. Also a slight decrease in rainfall during Pre-Monsoon (5.3%).	Low[4]	Low[5]	Low	**Direct impacts:** • Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out • Arable winter crops grown around the reservoir may be less productive **Indirect impacts:** • Fish production is dependent upon water level and area, so may decrease more rapidly	Medium[6]	Medium

[1]Large volume of water, high discharge and higher number of predators in the lowland rivers do not constitute a conducive environment for ova and fry of mahseer (Bhatt JP, Nautiyal P, Singh HR, 2004, Status (1993–1994) of the endangered fish Himalayan mahseer Tor putitora (Hamilton) (Cyprinidae) in the mountain reaches of the river Ganga. Asian Fish Sci 17:341–355)

[2]Large volume of water, high discharge and higher number of predators in the lowland rivers do not constitute a conducive environment for ova and fry of mahseer (Bhatt et al. 2004).

[3]Adaptive capacity may be direct relating to the natural habitat capacity of ecosystems and species or indirect relating to the management capacity. This a balance between the natural capacity of the wetland to adapt to increased rainfall and sediment, and the management capacity of the HPP dam to manage the flows and release of water in reservoir.

[4]The most accepted season for spawning in T. putitora is the high floods during monsoon (Nautiyal P, 1984, Natural history of the Garhwal Himalayan mahseer Tor putitora (Hamilton) II: breeding biology. Proc Indian Acad Sci 93:97–106).

[5]The most accepted season for spawning in T. putitora is the high floods during the monsoon (Nautiyal 1984).

[6]Reservoir water levels are regulated and so the drawdown can be managed by HPP.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the hot season/ Monsoon (Jun-Sep)	An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.	High[7]	High[8]	High[0]	**Direct impacts:** • Increase temperature will lead to higher evapotranspiration and high water withdrawals will greatly undermine the fish species diversity and distribution in the Pong dam. • Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species • Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l **Indirect impacts:** • Temperature change in the higher elevations may lead to species differentiation and divergence. • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water	Low[9]	Very High
Increase of temperature during the cold season (Oct-May)	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from 23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.	Medium[10]	Medium[11]	Medium	**Direct impacts:** • Increase temperature will lead to higher evapotranspiration and high water withdrawals will greatly undermine the fish species diversity and distribution in the Pong dam. • Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species	Low[12]	Medium

[7]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 (Bhatt et al. 2004).

[8]The fish prefers to continue in the main channel upstream, mostly with perennial water source and cooler temperatures (Nautiyal P, 1994, The Himalayan or putitor mahseer Tor putitora (Hamilton). In: Nautiyal P (ed) Mahseer the game fish. Jagdamba Publications, Dehradun, pp B4–B12)

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

[10]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 (Bhatt et al. 2004).

[11]The fish prefers to continue in the main channel upstream, mostly with perennial water source and cooler temperatures (Nautiyal 1994).

[12]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	Increase in frequency and magnitude of flooding during monsoon season	**High**[13]	**High**[14]	**High**	**Direct impacts:** • The fish species richness is primarily driven by the quantum of water discharge in the rivers. • Increase in turbidity and sediment in the reservoir from increased erosion will help from predators **Indirect impacts:** • Water quality will affect because of nutrient load. • Increased reservoir filling and area will enhance fish productivity.	**Medium**[15]	**High**
Drought	Increasing consecutive days of drought	**High**[16]	**High**[17]	**High**	**Direct impacts:** • Algae and Vegetation will also get affected. • Lower water level in the reservoir and lower soil moisture **Indirect impacts:** • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants	**Low**[18]	**High**

[13] Large volume of water, high discharge and higher number of predators do not constitute a conducive environment for ova and fry of mahseer (Bhatt et al. 2004).

[14] Fertilized eggs can sink and perish in the muddy beds of the dam.

[15] Being a rain fed hill streams, ecological requirements such as temperature ranges between 16 and 25 °C in river water with high turbidity may be met. Also the food of fish comprises insects, algae, macrophytes, rotifers, small fish, crustaceans, etc. (Badola and Singh 1980; Dasgupta 1991a).

[16] Due to drought conditions, the spawning grounds are shallow due to low water discharge during non-monsoon months and are most impacted by destructive fishing practices, like the use of cropping, grazing, and diversion of water (Everard and Kataria 2011).

[17] Fish lay eggs in shallow waters with 0.5–3.5 m depth with stream beds of gravel, pebbles, silt and sand (Pathani SS, 1994a, Biology of tor and putitor mahseer. In: Nautiyal P (ed) Mahseer the game fish. Jagdamba Publications, Dehradun, pp B86–B90)

[18] Overall Natural Adaptive capacity will be low. Algae and other vegetation matter constitute a fraction of fish food during winter and summer, but comprise most of the diet in the monsoon season.

Annex 3.5.1 – 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

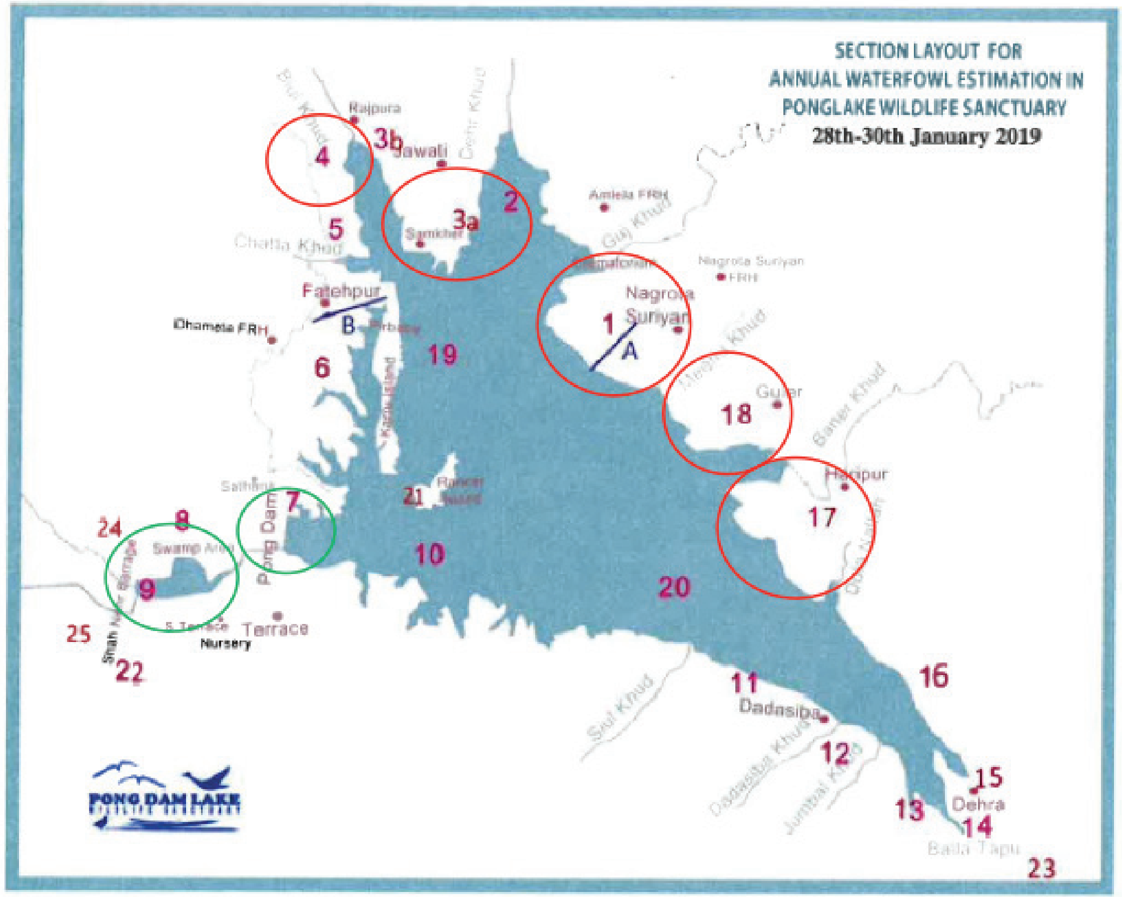
***Figure 2** Determining the vulnerability score from Impact and Adaptive capacity*

Annex 3.6 - Vulnerability Assessment Matrix for Migratory Bird Habitats

ASSET NAME: MIGRATORY BIRD HABITATS

ASSET DESCRIPTION: The most important habitat is found at Nagrota Surian which has 50% more than another location marked on the map below. More generally it is the Northern shoreline, flat shallow areas that retain aquatic plants and rhizomes, mudflats with access to arable land for lapwings and geese.

Preferred locations for migratory (left) and resident waterbirds (right) around Pong Dam[1]



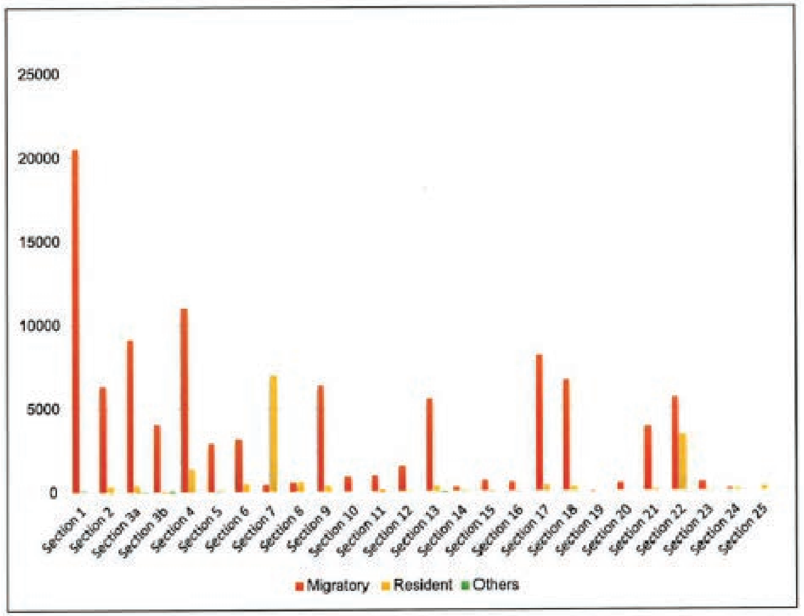


Fig 5: Graph representing Population of Water Dependent birds in different sections of Pong Dam Lake WLS

Section 1: Meenu Khud to Crematorium (Nagrota Surian Beat) - **20525**

Section 4: Biul to Chatta Watch Tower (Dhameta Beat) - **11029**

Section 3a: Dehar to Bathu Temple (Jawali Beat) - **9122**

Section 17: Dolla Nala to Baner (Bhatoli Phakorian Beat) - **8158**

Section 18: Meenu to Baner (Nagrota Surian Beat) - **6645**

1 Kumar, K., 2019. Annual waterfowl estimation report: Pong Dam wildlife sanctuary.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	Very High[2]	Medium[3]	Very High	**Direct impacts:** • Increased erosion in the catchment leads to increased sediment loads in the reservoir, smothering of aquatic plant habitat and shift of mudflat zones • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp. Regular violent releases could erode downstream wetland **Indirect impacts:** • Populations of migratory birds dependent upon aquatic plants may sustain reduced populations, e.g. teal • Geese and lapwings could benefit from increased arable production feed • Increased potential for power generation and downstream irrigation • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	Medium[4]	Very High
Decrease of rainfall during Winter (Jan-Feb) and pre- monsoon season (Mar-May)	Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the	High[5]	Medium[6]	High	**Direct impacts:** • Mudflat zones and aquatic vegetations will be more rapidly exposed and dry out. • Shallow water areas available for migratory birds feeding will be reduced or extend further into the reservoir.	Medium[7]	High

[2]Note that migratory habitats are exposed to wet season rainfall which maintains health of the habitat, even when the birds are not there.
[3]These areas are seasonally flooded by the reservoir, and water levels are maintained by the dam operation, so the sensitivity is medium. There may be an additional benefit of increased rainfall due to productivity of arable land. Sediment in the reservoir projected to increase from 23 to 26 MmT/year, 75% of which settle in live zone. Sedimentation from the increased erosion will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones, so the sensitivity is medium. May be a reduced habitat zone because the reservoir is filled quicker and more frequently during the wet season.
[4]Adaptive capacity may be direct relating to the natural habitat capacity of ecosystems and species or indirect relating to the management capacity. This a balance between the natural capacity of the wetland to adapt to increased rainfall and sediment, and the management capacity of the HPP dam to manage the flows and release of water in the reservoir.
[5]Decrease of 50 mm during the dry season may be important for these areas, especially when combined with increased temperatures, which will increase evapotranspiration and push the climate towards greater seasonal aridity. Decreased rainfall and increased temperatures in the dry season will increase demand for irrigation water releases, resulting in a more rapid drawdown.
[6]The migratory birds arrive in September/October and depart in February/March. The reservoir level will be beginning to decrease, exposing the shallow mudflat zone. The habitat would be progressively drawn down, but only fully exposed at end of the dry season. Area is used to adapted to drawing down but there may be increased demand for irrigation water.
[7]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
	catchment. Also a slight decrease in rainfall during Pre-Monsoon (5.3%).				• Arable winter crops grown around the reservoir may be less productive. **Indirect impacts:** • Migratory bird habitats may be slightly less attractive. • Fish production is dependent upon water level and area, so may decrease more rapidly.		
TEMPERATURE							
Increase of temperature during the hot season /Monsoon (Jun-Sep)	An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.	Very High[8]	High[9]	Very High	**Direct impacts:** • Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species • Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l • Increase in phytoplankton and associated zooplankton growth and cycles of death and decay • Algal blooms, possibly increase in blue-green algae • Riparian vegetation flourishes • Crops above reservoir tend not to grow so well unless irrigated **Indirect impacts:** • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water • Increased food supply for dabbling and diving ducks in autumn • Need to change the selection of crops to those more suited to higher temperatures	Low[10]	Very High

[8] A remarked increase in maximum and average temperatures will shift bioclimate zone of Pong Dam from Hot and mesic, towards extremely hot and arid.

[9] Shallow water habitats around the reservoir will heat up and are often already very high (surface water temp recorded up to 40oC). Dissolved O2 conc. is already showing a downward trend. Aquatic vegetation and phytoplankton may be enhanced, but riparian and terrestrial vegetation and crops will increase evapotranspiration and may not grow so well. Evaporation from the reservoir surface will be increased.

[10] No possibility of natural adaptation to this range of high tempuratures. Possible to reduce the water temperature through sheltering (e.g. floating solar) or through planting of riparian trees, and improving water quality through mechanical water aeration in the reservoir (but expensive).

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the cold season (Oct-May)	Increase 2.8ºC during winter (Jan-Feb), the average temperature increasing from 9.6 to 12.4ºC. Increase 1.8ºC during pre-monsoon (Mar-May), the average temperature increasing from 23.9 to 25.7ºC. Increase 3.3ºC during post-monsoon (Oct-Dec), the average temperature increasing from 15.6 to 18.9ºC.	High[11]	High[12]	High	**Direct impacts:** • Continued plant and phytoplankton growth and zooplankton through winter • More food for dabbling and diving ducks • Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants **Indirect impacts:** • Will migratory birds tend to stay in their breeding habitats if these also get warmer in winter, with reduced migration?	Low[13]	High
EXTREME EVENTS							
Flood	Increase in frequency and magnitude of flooding during monsoon season	High[14]	High[15]	High	**Direct impacts:** • Increase in sediment in the reservoir from increased erosion • Shifts of mudflat zones • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp. **Indirect impacts:** • Flood will lead to closing to ites • Water quality will affect because of nutrient load. • Increased potential for power generation and downstream irrigation • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	Medium[16]	High

[11]Fewer frosts, more warm days

[12]Will allow more temperature sensitive plants to survive, may bring on crops and plants in spring time and at end of the dry season so that they start growing earlier. This is the season for migratory birds, they may feel too hot to stay in their breeding areas.

[13]Natural adaptive capacity includes shifts in plant species or reduced need for migration. The management capacity is low to address these changes.

[14]Submergence of breeding sites of migratory birds and aquatic plant habitat and shift of mudflat zones.

[15]Flooding will bring more sediment in the reservoir from the increased erosion and will tend to shift the shallow zones more towards the deeper parts of the lake, reducing the current mudflats zones, so the sensitivity is high. Maybe a reduced habitat zones. However, water levels are regulated & can be managed by HPP.

[16]Reservoir water levels are regulated and can be managed by HPP in case of flood. Adaptive capacity may be direct relating to the natural habitat capacity of ecosystems and species or indirect relating to the management capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Flash flooding	Occurs during monsoon – mid-July to mid-August not later in the wet season	Low[17]	Low[18]	Low	**Direct Impacts** • Sediment smothering of upper areas of the reservoir but the trends in past 10 years show little changes these areas • With increased degradation of the catchment, flash flooding is likely to increase with an increase in sediment **Indirect impacts** • Downstream impacts flooding can be very significant	High[19]	Low
Drought	Increasing consecutive days of drought	Low[20]	Low[21]	Low	**Direct impacts:** • Vegetation will also get affected. • Lower water level in the reservoir and lower soil moisture **Indirect impacts:** • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants	Medium[22]	Medium
Wind	Increase in high wind events and wind speed in autumn and winter	High[23]	Medium[24]	High	**Direct impacts:** • Disturbance of migratory birds especially on northeastern shore in afternoons – may cause shifts of birds to more sheltered bays	Very Low[25]	Very High

[17]Exposure low because migratory birds will not be present during the flooding seasons. Expanse of habitat area is so large that even flash flooding will be absorbed.

[18]Because migratory birds will not be present during the flooding seasons. Expanse of habitat area is so large that even flash flooding will be absorbed. Water levels in reservoir can absorb any flooding that may happen.

[19]Natural Adaptive capacity quite high because the absence of migratory birds during this time.

[20]Migratory birds will not be present during the drought seasons especially Mar-Sep. If there is a drought during Oct-Mar, habitat & breeding sites will be affected due to low water levels. Therefore, exposure will be low.

[21]Migratory birds will not be present during the drought seasons especially Mar-Sep. If there is a drought during Oct-Mar, habitat & breeding sites will be affected due to low water levels. Therefore, exposure will be low.

[22]Overall Natural Adaptive capacity will be medium because (1) the absence of migratory birds during Mar- Sep, if there is a drought -High (2) If there is a drought during Oct- Mar and migratory birds are present, then the adaptive capacity is low, therefore, resulting an overall score of medium.

[23]Autumn starts from mid-September to mid-December, when migratory birds arrive. The frost and wind are common during this period. The wind in the area of Pong reservoir is of utmost importance in the forenoon of the winter season the wind movements are generally from the east to the western side. The Pong reservoir being the huge water body experiences the rising waves depending upon the wind velocity. Sometimes, wind velocity goes up to 100 nautical miles per hour.

[24]Aquatic plants, trees may get damages if there is a high speed of wind.

[25]Little that can be done naturally or management except for providing safer fishing and boating craft.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Erosion of shoreline on the northeastern shore • Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills **Indirect impacts:** • High winds and large waves will make boating more challenging for fishing activities and reduce tourist attraction at some times of day		

Photo credit: CarrotFilms.GIZ

Annex 3.6.1 – 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*

Annex 3.7 - Vulnerability Assessment Matrix for Fisheries

ASSET NAME: FISHERIES

ASSET DESCRIPTION: Pong reservoir has a huge potential of fisheries resources with an average water spread area of 15000 ha. Pong provides nutritional and livelihood support to many poor fishermen who are fully dependent on Pong reservoir resources.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Sep)	Increase by 17.7%, from 1479.8 mm to 1741.9 mm (+262.1 mm) by 2050s. More significant increases for immediate upstream areas in the catchment.	High[1]	Medium[2]	High	**Indirect impacts:** • Excess sediments can cause damage by blocking light that allows algae (an important food source) to grow, harming fish gills, harming important habitats and stopping fish from seeing well enough to move around or feed. • Sediment can clog fish gills, reducing resistance to disease, lowering growth rates, and affecting fish egg and larvae development. • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp. **Indirect impacts:** • Increasing water spread area will lead to rich flora and fauna • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants • Increased potential for power generation and downstream irrigation	High[3]	Medium

[1]There is a closed season of fishing from 15 June to 15 August in the reservoir when fishing is banned (ICAR, 2021. Assessment and management of fisheries resources of Pong Reservoir, Himachal Pradesh. Barrackpore-700120, Kolkata, West Bengal, India.). The majority of fishes breed during the monsoon months, i.e. June to August because of their dependence on seasonal floods, which inundate the floodplain areas essential for reproduction and feeding. A decrease in precipitation during the breeding months alters the required flow and turbidity of the water essential for breeding of Indian Major Carps (IMC) and a consequent decline in fish spawn availability (Vass, K.K., Das, M.K., Srivastava, P.K., Dey, S., 2009. Assessing the impact of climate change on inland fisheries in River Ganga and its plains in India. Aquat. Ecosyst. Health Manag. 12, 138–151).

[2]Rainfall showed a mild positive relationship with the fish production (ICAR, 2021). Sediment in the reservoir is projected to increase from 23 to 26 MmT/year. Concentration of the suspended particles shall raise in the future, which would adversely affect the growth and yield of many fishes which are found in the Pong wetland area and sediment can clog fish gills, affecting fish egg and larvae development (INRM, 2020. Modeling Climate and Hydrological Risks Associated with Ecosystem Functioning of Pong Reservoir, Himachal Pradesh. Report for GIZ India.). Therefore, the sensitivity is medium.

[3]Adaptive capacity will be high because of increased rainfall and sediment, and the management capacity of the HPP dam to manage the flows and release of water in the reservoir.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during Winter (Jan-Feb) and pre- monsoon season (Mar-May)	Decrease by 10.7%, from 170.9 mm to 152.6 mm (-18.3 mm) during Winter by 2050s. More significant decrease for immediate upstream areas in the catchment. Also a slight decrease in rainfall during pre-monsoon (5.3%).	**High**[4]	**Low**[5]	**Medium**	**Direct impacts:** • Aquatic vegetation will be more rapidly exposed and dry out • The shallow water area available will be reduced or extend further into the reservoir • Arable winter crops grown around the reservoir may be less productive **Indirect impacts:** • Fish production is dependent upon water level and area, so may decrease more rapidly	**Medium**[6]	**Medium**
TEMPERATURE							
Increase of temperature during the hot season/ Monsoon (Jun-Sep)	An increase of 3.1ºC for the SW Monsoon (from 24.1ºC to 27.2ºC) is projected. The temperature of the warmest month will increase by about 4ºC.	**High**[7]	**High**[8]	**High**	**Direct impacts:** • Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l • Increase in phytoplankton and associated zooplankton growth and cycles of death and decay • Algal blooms, possibly increase in blue-green algae • Crops above reservoir tend not to grow so well unless irrigated **Indirect impacts:** • Potential increase in fish mortality due to increased surface temperatures and anaerobic conditions in deeper water	**Low**[9]	**High**

[4]Decrease of 50 mm during the dry season may be important for these areas, especially when combined with increased temperatures, which will increase evapotranspiration and push the climate towards greater seasonal aridity. Decreased rainfall and increased temperatures in the dry season will increase demand for irrigation water releases, resulting in a more rapid drawdown.

[5]The reservoir level will be beginning to decrease and the habitat would be progressively drawn down, but only fully exposed at end of the dry season.

[6]Reservoir water levels are regulated and so draw down can be managed by HPP, within the constraints of demand for electricity and irrigation

[7]Water temperature is particularly important for maturation and breeding of fish. Annual mean temperature did not show any significant relationship with the annual fish production (ICAR, 2021). A marked increase in maximum and average temperatures will shift the bioclimate zone of Pong Dam from Hot and mesic, towards extremely hot and arid.

[8]Fish yield is dependent on temperature, concentration of the suspended and settled solids and chemical parameters like pH, alkalinity, hardness and metals. Concentration of the suspended particles shall raise in future, which would adversely affect the growth and yield of many fishes which are found in Pong wetland area (INRM, 2020).

[9]No possibility of natural adaptation to this range of high temperatures. Possible to reduce water temperatures through sheltering (e.g. floating solar) or through planting of riparian trees, and improving water quality through mechanical water aeration in the reservoir (but expensive).

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					• Need to change the selection of crops to those more suited to higher temperatures		
EXTREME EVENTS							
Flood	Increase in frequency and magnitude of flooding during monsoon season.	**High[10]**	**Medium[11]**	**High**	**Direct impacts:** • Fish culture facilities will be impacted by damage to the facilities, loss of fish stock and introduction of fish predators and disease germs. • Operational costs of the facilities will increase. • Increase in sediment in the reservoir from increased erosion • Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp. **Indirect impacts:** • The large input of organic matter to aquatic floodplain • Habitats may reduce dissolved oxygen and result in the emigration or death of a great number of fish. • Water quality will affect because of nutrient load. • Increased potential for power generation and downstream irrigation • Increased reservoir filling and area will enhance fish productivity and hence resident birds e.g. cormorants	**Medium[12]**	**High**

[10]Fishery is observed that there is decline in the fish yield as seen after 1988 flood (INRM, 2020). Regular, predictable annual flooding ensures reproductive success; most tropical fishes leave the main river channel and enter the inundated floodplain to spawn (Harper D, Mavuti K (1996) Freshwater wetlands. In: McClanahan RR, Young TP (eds) East African ecosystems and their conservation. Oxford University Press, New York). Also submergence of aquatic plant habitat.

[11]Flooding will bring more sediment in the reservoir from the increased erosion and may reduce dissolved oxygen. Maybe a reduced habitat zone.

[12]Reservoir water levels are regulated and can be managed by HPP in case of flood.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Drought	Increasing consecutive days of drought	**High**[13]	**High**[14]	**High**	**Direct impacts:** • Vegetation and crops will get affected. • Lower water level in the reservoir and lower soil moisture **Indirect impacts:** • The impact on the culture ystem will reflect reduced water quality and limitations in the culturable water area and volume. As a result, there will be a loss in fish production • Will also increase the depletion of water and degradation of the catchment. • Reduced bio-mass and aquatic plants • Less food for bar-headed geese	**Low**[15]	**High**
Wind	Increase in high wind events and wind speed in autumn and winter	**High**[16]	**Medium**[17]	**High**	**Direct impacts:** • A large quantity of zooplankton and phytoplankton organisms are accumulated near the downwind shoreline due to wind currents. • The wind blows phytoplankton, zooplankton, aquatic insects and terrestrial insects toward the windward shore which attracts crustaceans and baitfish. • These baitfish attract larger predator species that feed on them.	**Very Low**[18]	**Very High**

[13]Fish habitat/refugia may dry out and the size and quality of habitat/refugia decrease, thereby creating the conditions for the occurrence of high fish mortality and the reduction of abundances in subsequent seasons/years (Magalha˜es M.F., Schlosser I.J. & Collares-Pereira M.J. 2003. The role of life history in the relationship between population dynamics and environmental variability in two Mediterranean stream fishes. Journal of Fish Biology, 63, 300–317).

[14]A decrease in precipitation during the breeding months alters the required flow and turbidity of the water essential for breeding of Indian Major Carps (IMC) and a consequent decline in fish spawn availability (Vass et al., 2009).

[15]Overall Natural Adaptive capacity will be medium because of low water levels.

[16]Wind speed can either negatively or positively affect the quality of the fishing. The Pong reservoir being the huge water body experiences the rising waves depending upon the wind velocity. Sometimes, wind velocity goes up to 100 nautical miles per hour.

[17]Aquatic plants, trees may get damaged if there is a high speed of the wind and a higher number of wind events.

[18]Little that can be done naturally or management except for providing safer fishing and boating craft.

Threat category	Details of threat					Adaptive capacity	Vulnerability
		Exposure	Sensitivity	Impact level	Impact summary		
EXTREME EVENTS							
					• Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills **Indirect impacts:** • High winds and large waves will make boating more challenging for fishing activities and reduce tourist attraction at some times of day		

Photo credit: CarrotFilms.GIZ

Annex 3.7.1 – Scoring matrices

		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	High
	Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

		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 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 4 – LIST OF ADAPTATION PLANNING MATRICES

Table 32 *Adaptation Planning Matrices*

Target asset	Attached file
Pong Dam Hydel project	AAS2010-REP-003-02 Final Report PongDam (Annex 4.1 AP_Pong Hydel).docx
Catchment area	AAS2010-REP-003-02 Final Report PongDam (Annex 4.2 AP_Catchment).docx
Pong Reservoir	AAS2010-REP-003-02 Final Report PongDam (Annex 4.3 AP_Pong Reservoir).docx
Bar-headed goose (BHG) and Northern Pintail (NP)	AAS2010-REP-003-02 Final Report PongDam (Annex 4.4 AP_BHG&NP).docx
Golden Mahseer *(T. putitora)*	AAS2010-REP-003-02 Final Report PongDam (Annex 4.5 AP_Golden Mahseer).docx
Migratory birds	AAS2010-REP-003-02 Final Report PongDam (Annex 4.6 AP_ Migratory Bird Habitats).docx
Fisheries	AAS2010-REP-003-02 Final Report PongDam (Annex 4.7 AP_Fisheries).docx

Photo credit: CarrotFilms.GIZ

Annex 4.1 - Adaptation Planning Matrix for the Pong Dam Hydel

ASSET NAME: PONG DAM HYDEL

ASSET DESCRIPTION: Pong dam stored water is primarily used for meeting irrigation water demands for which a total of 7913 Mm3 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.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during Winter (Jan-Feb) - **High**	Reservoir level low and water availability will be less for hydropower generation and irrigation.	Explore, redesign, improve, remove physical structures which are barriers to flows and floodwaters	Medium[1]	Medium[2]	Medium
		Study irrigation options for coordination of irrigation schemes for maximum efficiency and minimum impacts	High[3]	High[4]	High
	Arable winter crops grown around the reservoir may be less productive.	Fund establishment for winter crops insurance	Medium[5]	Medium[6]	Medium
		Research and development on climate-resilient crops	High[7]	High[8]	High
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) - **Very High**	Snow and glacier melt runoff in Beas catchment were studied for the years 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).	Explore, redesign, improve, remove physical structures which are barriers to flows and floodwaters	High[9]	Medium[10]	Medium
		Increase vegetation cover in surrounding areas of the lake to reduce evaporation and erosion.	Medium[11]	Medium[12]	Medium

[1]As all physical structures can't be removed, as these satisfy domestic and irrigation water demands and also help groundwater recharge.
[2]Impact can be reduced only partially.
[3]Highly feasible and can be implemented immediately without additional R&D.
[4]Impact can be reduced to a large extent.
[5]Moderate feasibility, as it includes policy level changes and may be suitable in long-term.
[6]Ensuring farmer's security will strengthen partnerships with government, and livelihood security will play a crucial role in agriculture development in the region in long-term.
[7]Climate-resilient crops measure is highly feasible; however, it would require comprehensive R&D and can be successful in the long-run.
[8]Through this measure, the impact can be reduced to a large extent.
[9]With some additional R&D, it can be implemented.
[10]It has the potential of reducing the impact to a large extent
[11]It is a long-term measure and quite feasible with help of coordination from different government agencies.
[12]Impact can be reduced only moderately.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Average annual maximum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.5°C towards mid-century and by 2.8°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.3°C towards end-century for Pong Basin State	Explore, redesign, improve, remove physical structures which are barriers to flows and floodwaters to allow natural adaptation of habitats	Medium[13]	Medium[14]	Medium
	Average annual minimum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.7°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.0°C towards end-century for Pong Basin State. Thus, the projected temperature increase towards EC is higher than that of MC.	Avoid building infrastructure which prevents or obstruct free flows, floodwaters, routes, and migration of fish and other aquatic animals	Medium[15]	High[16]	High
	Due to a high daily difference in temperature between the surface and near-surface areas of the dam, surface cracks may be developed. Cracks adversely affect water tightness, durability and therefore, are undesirable.	Put flooded forests and associated wetlands in Protected Areas System	High[17]	High[18]	High
		Prevent soil and bank erosion through increasing land cover, regenerate and replanting native trees where possible on riverbanks and islands.	Medium[19]	High[20]	High

[13]It is a long-term project, Various case studies supporting the action plan are mentioned in Barange et al., 2018, Impacts of climate change on fisheries and aquaculture: synthesis of currrent knowledge, adaptation and mitigation options, FAO.
[14]Impact can be reduced only moderately.
[15]It can be done immediately wo additional R & D, however avoiding building infrastructure wholesomely won't be feasible due to human water demands.
[16]Impact can be reduced to a large extent.
[17]It is a immediate measure and quite feasible with help of coordination from different government agencies.
[18]Impact can be reduced to a large extent.
[19]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan (Moore et al., 1988. Lake and reservoir restoration guidance manual (No. PB-88-230719/XAB). North American Lake Management Society, Merrifield, VA, USA).
[20]Through this measure, the impact can be reduced to a large extent.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Surface water temperature increases will enhance evaporation losses and the working of hydraulic machines.	Maintaining the hydrological characteristics and environmental flows, need to be studied and monitored in the long term.	Medium[21]	High[22]	High
	Surface water temperature increases during summer, possibly beyond threshold limits for vegetation and some aquatic species	Maintaining the hydrological characteristics and environmental flows, need to be studied and monitored in the long term.	Medium[23]	High[24]	High
	Crops above reservoir tend not to grow so well unless irrigated	Study irrigation options for coordination of irrigation schemes for maximum efficiency and minimum impacts	High[25]	High[26]	High
		Research and development on climate-resilient crops	High[27]	High[28]	High
Increase of temperature during the cold season (Oct-May) -**High**	Increase in evapotranspiration and less power generation.	Restore certain key degraded habitats, such as regeneration of flooded forests, re-vegetation of riparian forests and tree-planting	Medium[29]	High[30]	High

[21]It is a long-term project, Various case studies supporting the action plan are mentioned in Barange et al., 2018.
[22]Impact can be reduced significantly, however would take a long time.
[23]It will require additional R & D on the hydrological system and it is a long-term measure.
[24]Impact can be reduced significantly.
[25]Study on irrigation system is required as mentioned in ICEM, 2013. Case Study: Xe Champone Wetlands, Basin-wide Climate Change Impact and Vulnerability Assessment for Wetlands in the Lower Mekong Basin for Adaptation Planning. Consultant report prepared for the Mekong River Commission, Hanoi, Viet Nam.
[26]Impact can only be reduced significantly.
[27]Climate resilient crops is the most feasible, as it can be implemented wo additional R&D, however would require awareness programmes for farmers.
[28]Impact can be reduced significantly.
[29]It is a long-term project, Various case studies supporting the action plan are mentioned in Barange et al., 2018.
[30]Impact can be reduced significantly, however would take a long time.

Annex 4.1.1 - 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: CarrotFilms.GIZ

Annex 4.3 - Adaptation Planning Matrix for the Pong Reservoir

ASSET NAME: PONG RESERVOIR

ASSET DESCRIPTION: Open deep water, Shallow water in drawdown, Dry sandbanks with little or no vegetation, Waterside vegetation and swamps below the out-fall from the dam

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) – **Very High**	Increased areal water extent will lead to disturbances in the ecosystem through changes in water quality, turbidity, dissolved oxygen, surface water temperature and depth profiles of the aerobic layer.	Exploring more resilient and adaptive species that are capable to withstand these disturbances.	High[1]	Medium[2]	Medium
		Installation of devices to assess water quality, turbidity, dissolved oxygen, surface water temperature etc.	High[3]	Medium[4]	Medium
	Increased erosion in the catchment leads to increased sediment loads in the reservoir.	Conservation of remaining forest areas within the catchment	Medium[5]	Medium[6]	Medium
		Watershed management program with communities	High[7]	Medium[8]	Medium
		Piloting the growing of crops in drawdown areas for a win-win (to be assessed over time; could only continue under strict standards and controls - e.g., the use of agricultural chemicals)	High[9]	Medium[10]	Medium
	Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp.	Construction of retention reservoir to control flooding	Medium[11]	High[12]	High

[1]Implementation is technically feasible without any additional R&D and can be implemented immediately (Moritz et al., 2013. The future of species under climate change: resilience or decline?. Science, 341(6145), 504-508).
[2]Can only avoid the impact partially.
[3]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Mizuno et al., 2009. Instrumentation and monitoring of dams and reservoirs. Water Storage Transp. Distribution, 1, 1-8.)
[4]Can only avoid the impact partially.
[5]Conservation is feasible without additional R&D but will require a long time period owing to the size of the catchment. Studies supporting the action plan. (Biao et al., 2010. Water conservation of forest ecosystem in Beijing and its value. Ecological economics, 69(7), 1416-1426.)
[6]The impact can only be partially avoided and the adaptation will take long time.
[7]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan. Study supporting the action plan (Moore, L., & Thornton, K., 1988. Lake and reservoir restoration guidance manual (No. PB-88-230719/XAB). North American Lake Management Society, Merrifield, VA, USA).
[8]It will deal with the impact partially.
[9]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Kunisue et al., 2003. Accumulation features of persistent organochlorines in resident and migratory birds from Asia. Environmental pollution, 125(2), 157-172).
[10]Can only avoid the impact partially and might also impact the population living downstream
[11]The implementation of the procedure to the reservoir of a large size like Pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment. (Patro, M., 2008. Influence of in-field retention reservoirs on soil outflow from a catchment. Annals of Warsaw University of Life Sciences-SGGW. Land Reclamation, 39.)
[12]Can remove the impact significantly.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during Winter (Jan-Feb) – **Very High**	Drawn down exposes sandbanks, which can be potential nesting sites.	Prohibiting nesting of the local inhabitants in the nearby areas of the reservoir.	Medium[13]	Medium[14]	Medium
	Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out	Implementation of flood control management system for the pong reservoir (which includes (1) data collection, (2) observed data validation and processing, (3) reservoir forecasting, (4) flood control operation and (5) information inquiry)	High[15]	High[16]	High
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) – **Very High**	Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species	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.	High[17]	Medium[18]	Medium
		Exploring more resilient and adaptive aquatic species that are capable to withstand these disturbances.	High[19]	Medium[20]	Medium
	Riparian and aquatic vegetation flourishes. Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l	Plant tall bushes or trees around the outside of the pond to shade the water.	High[21]	Medium[22]	Medium

[13]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost-effective and the involvement of local communities will enhance the effectiveness of the plan.
[14]It will deal with the impact partially.
[15]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K., 2004. Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267).
[16]Impact can be avoided completely and this adaptation will serve for a long period.
[17]It is technically feasible, can be implemented immediately and is cost-effective. Government has significant skills and institutional arrangements to support this action. (Oron, G., 1990. Economic considerations in wastewater treatment with duckweed for effluent and nitrogen renovation. Research Journal of the Water Pollution Control Federation, 692-696).
[18]Can only avoid the impact partially.
[19]The implementation is technically feasible without any additional R&D and can be implemented immediately (Moritz et al., 2013).
[20]Can only avoid the impact partially.
[21]It is technically feasible, can be implemented immediately and is cost-effective. Government has significant skills and institutional arrangements to support this action. (Castelletti, A., Galelli, S., Restelli, M., & Soncini-Sessa, R., 2010. Tree-based reinforcement learning for optimal water reservoir operation. Water Resources Research, 46(9).)
[22]Can only avoid the impact partially and will take a long time for the trees to grow.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
		Increasing the contact of water with air using mechanical ways such as diffusers.	Medium[23]	High[24]	High
		Establishment of precise devices in the reservoir to continuously monitor DO levels.	High[25]	Medium[26]	Medium
	Significant increase in evaporation losses	Covering the surface of water bodies with a fixed or floating cover considerably reduces evaporation losses	Medium[27]	High[28]	High
EXTREME EVENTS					
Flood - **High**	Flood should not have a significant impact on the reservoir as it is an inundated area and the water level is regulated.	Construction of retention reservoir to control flooding	Medium[29]	High[30]	Medium
		Implementation of flood control through a system of reservoirs	Medium[31]	High[32]	High
	Areal water extent increase at an intense rate led to disturbances and others.	Reforestation, diversion dams and measures can be taken at the reservoir inflow.	Medium[33]	Medium[34]	Medium
	Increase in sediment in the reservoir by erosion	Soil conservation measures. Creating a network of hydro met stations and silt traps to assess the extent of the problem	High[35]	Medium[36]	Medium

[23]The implementation of the procedure to the reservoir of a large size like Pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment. (Mobley, M. H., and Brock, W. G., 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234).

[24]Can remove the impact significantly.

[25]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J., 2018. Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450).

[26]It can only deal with the impact partially.

[27]The implementation of the procedure to the reservoir of a large size reservoir like Pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment.

[28]Can remove the impact significantly and can be implemented in a short period of time.

[29]The implementation of the procedure to the reservoir of a large size reservoir like Pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment.

[30]Can remove the impact significantly.

[31]This is an action research to assess the effectiveness of adaptation measures in the affected areas. The extent to this measure can be rolled out will be compromised by other interests concerned with maintaining water volume in the reservoir. The planting could be restricted to the drawdown areas. (Chang, L. C., Chang, F. J., & Hsu, H. C., 2010. Real-time reservoir operation for flood control using artificial intelligent techniques. International Journal of Nonlinear Sciences and Numerical Simulation, 11(11), 887-902).

[32]Impact can be avoided completely and this adaptation will serve for a long period.

[33]Additional R&D will be required, and cannot be implemented immediately. (Miller, J. R., Sinclair, J. T., & Walsh, D., 2015. Controls on suspended sediment concentrations and turbidity within a reforested, Southern Appalachian headwater basin. Water, 7(6), 3123-3148).

[34]It will indirectly avoid the impact and the extent will be partial.

[35]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M., 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418).

[36]Can only avoid the impact partially.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Decrease in D.O and water quality due to organic matter and sediment run-off in flood water	Increasing the contact of water with air using mechanical ways such as diffusers.	Medium[37]	High[38]	High
Drought - High	Increased demand for irrigation water from the reservoir	Irrigation schemes can be developed to reduce the impact of drought	High[39]	Medium[40]	Medium
		Cropping pattern change during years of expected drought	High[41]	Medium[42]	Medium
	Lower water level in the reservoir.	Regulation of water level in the reservoir based on the possible impact of drought	High[43]	Medium[44]	Medium
	Potential for algal blooms and reduce water quality	Installation of vertical curtains to reduce the nutrient loading in the reservoir	Medium[45]	Medium[46]	Medium
Wind - High	Erosion of shoreline on the north-eastern shore	Bunds can be constructed to reduce the erosion on the North-Eastern shoreline	High[47]	Medium[48]	Medium
	Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills	Continuous monitoring of fish health in the reservoir and documentation of events where a large number of fish die during a period.	High[49]	Medium[50]	Medium

[37]The implementation of the procedure to the reservoir of large size like Pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment. (Mobley, M. H., and Brock, W. G., 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234).
[38]Can remove the impact significantly.
[39]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.
[40]It will indirectly avoid the impact and the extent will be partial.
[41]It is technically feasible, can be implemented immediately and is cost-effective. The implementation will require support from the local communities
[42]It will partially reduce the impact.
[43]It is technically feasible, can be implemented immediately and is cost-effective. Government has significant skills and institutional arrangements to support this action.
[44]Can only remove the impact partially.
[45]It is technically feasible with little R&D. Additionally, it is cost-effective and can be implemented in short period of time. (Asaeda, T., Priyantha, D. N., Saitoh, S., & Gotoh, K., 1996. A new technique for controlling algal blooms in the withdrawal zone of reservoirs using vertical curtains. Ecological Engineering, 7(2), 95-104).
[46]Can remove the impact significantly.
[47]It is technically feasible, can be implemented immediately and is cost-effective. Government has significant skills and institutional arrangements to support this action.
[48]It will indirectly avoid the impact and the extent will be partial.
[49]The implementation is technically feasible without any additional R&D and can be implemented immediately.
[50]Can only avoid the impact partially.

Annex 4.3.1 - Scoring of feasibility and effectiveness for prioritising adaptation options

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

Photo credit: KunalBharat.GIZ

Annex 4.4 - Adaptation Planning Matrix for Bar-headed Geese and Northern Pintail

ASSET NAME: BAR-HEADED GEESE AND NORTHERN PINTAIL

ASSET DESCRIPTION: Bar-headed Geese (> 45% world's population) and Northern Pintail are seen in the large congregations in this wetland. Bar-headed geese are herbivores (graminivores, granivores) and feed mainly on grasses that surround lakes where they nest. They also eat corn, barley, rice, wheat, and occasionally will take mollusks, insects, and crustaceans. In 2020, the total count of these birds at the lake was 29,443 while in 2021, 49,496 bar-headed geese have visited the lake. Bar Headed Geese breed in high-altitude wetlands that are up at 4,000 to 5,000 meters.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **Very High**	Increased sedimentation in the reservoir due to augmented erosion would smother aquatic habitat and shift of mudflat zones.	Creating additional habitat diversity with the addition of perched wetland, mounds and depressions, within drawdown areas (also could be tested downstream of the reservoir)	High[1]	Medium[2]	Medium
		Protection of first and second-order streams through bunding and check-dams	Medium[3]	High[4]	High
	Downstream flooding due to frequent water releases from the reservoir can affect the D/S wetland habitat of these birds.	Formulation of strict guidelines on discharge through the reservoir	High[5]	High[6]	High
Decrease of rainfall during Winter (Jan-Feb)- **High**	Drawn down exposes sandbanks, which can be potential nesting sites.	Creating additional habitat diversity with the addition of perched wetland, mounds and depressions, within drawdown areas (also could be tested downstream of the reservoir)	High[7]	Medium[8]	Medium
	Slightly less attractive habitats for these migratory birds.	Put flooded forests and associated wetlands in Protected Areas System	High[9]	High[10]	High

[1] It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Hollander, F. A., Van Dyck, H., San Martin, G., & Titeux, N., 2011. Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PloS one, 6(9), e25703.)

[2] Can only avoid the impact partially.

[3] Protection is feasible without additional R&D but will require a long time period owing to the size of the catchment and will require a large capital investment. (Abedini, M., Said, M. A. M., & Ahmad, F., 2012. Effectiveness of check dam to control soil erosion in a tropical catchment (The Ulu Kinta Basin). Catena, 97, 63-70.)

[4] Protection procedures will take long time but will help in removing the impact completely.

[5] Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K., 2004. Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267.)

[6] Impact can be avoided completely and this adaptation will serve for a long period.

[7] It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Hollander, F. A., Van Dyck, H., San Martin, G., & Titeux, N., 2011. Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PloS one, 6(9), e25703.)

[8] Can only avoid the impact partially.

[9] It is an immediate measure and quite feasible with help of coordination from different government agencies.

[10] Impact can be reduced to a large extent.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	Shallow water area available for bird feeding will be reduced or extend further into the reservoir	Identification of areas more frequently used for breeding and conserving these areas	High[11]	High[12]	High
	Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out	Study changes in hydrology, vegetation cover and sedimentation, e.g., impacts on mudflats, sand bars, water quality.	Medium[13]	High[14]	High
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) – **Very High**	During summer, surface water temperature increases, possibly beyond threshold limits for some aquatic species.	Avoid building infrastructure which prevents or obstruct free flows, floodwaters, routes, and migration of fish and other aquatic animals	Medium[15]	High[16]	High
	With the increase in temperature, dissolved oxygen in water decreases even below the threshold levels of 5 mg/l Increasing phytoplankton and associated zooplankton growth and algal blooms, possibly an increase in blue-green algae.	Re-introduce a more natural hydrological regime for the wetland system, using existing infrastructure	Medium[17]	High[18]	High
		Study changes in hydrology and sedimentation, e.g., impacts on mudflats, sand bars and water quality.	Medium[19]	High[20]	High

[11]It is technically feasible with little R&D. Additionally, it is cost-effective and can be implemented in short period of time.

[12]Impact can be avoided completely and this adaptation can be applied immediately.

[13]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M., 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418.)

[14]Impact can only be reduced significantly.

[15]It can be done immediately without additional R & D, however avoiding building infrastructure wholesomely won't be feasible due to human water demands.

[16]Impact can be reduced to a large extent.

[17]It is a long-term project, various case studies supporting the action plan are mentioned in Barange, M., Bahri, T., Beveridge, M.C., Cochrane, K.L., Funge-Smith, S. and Poulain, F., 2018. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO.

[18]Impact can be reduced significantly, however would take a long time.

[19]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M., 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418.)

[20]Impact can only be reduced significantly.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Crops above reservoir tend not to grow so well unless irrigated	Study irrigation options for coordination of irrigation schemes for maximum efficiency and minimum impacts	High[21]	High[22]	High
Increase of temperature during the cold season (Oct-May) - **High**	Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants	Formulation of strict guidelines on discharge through the reservoir	High[23]	Medium[24]	Medium
	Reduced migration of these birds due to increased winter temperatures	Put flooded forests and associated wetlands in Protected Areas System	High[25]	High[26]	High
FLOOD					
Increase in frequency and magnitude of flooding during monsoon season - **High**	Shifts of mudflat zones	Study changes in hydrology, vegetation cover and sedimentation, e.g., impacts on mudflats, sand bars, and water quality	Medium[27]	High[28]	High
	Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp	Implementation of flood control through the system of reservoirs	Medium[29]	High[30]	High
	Increased reservoir filling and area will enhance fish productivity	Protection of first- and second-order streams through bunding and check-dams	Medium[31]	High[32]	High

[21]Study on irrigation system is required as mentioned in ICEM, 2013. Case Study: Xe Champone Wetlands, Basin-wide Climate Change Impact and Vulnerability Assessment for Wetlands in the Lower Mekong Basin for Adaptation Planning. Consultant report prepared for the Mekong River Commission, Hanoi, Viet Nam.
[22]Impact can only be reduced significantly.
[23]It is technically feasible, can be implemented immediately and is cost effective. Implementation will require support from the local communities.
[24]It will partially reduce the impact
[25]It is an immediate measure and quite feasible with help of coordination from different government agencies.
[26]Impact can be reduced to a large extent.
[27]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M., 1953).
[28]Impact can only be reduced significantly.
[29]This is an action research to assess the effectiveness of adaptation measures in the affected areas. The extent to this measure can be rolled out will be compromised by other interests concerned with maintaining water volume in the reservoir. The planting could be restricted to the drawdown areas. (Chang, L. C., Chang, F. J., & Hsu, H. C., 2010. Real-time reservoir operation for flood control using artificial intelligent techniques. International Journal of Nonlinear Sciences and Numerical Simulation, 11(11), 887-902.)
[30]Impact can be avoided completely and this adaptation will serve for a long period.
[31]Protection is feasible without additional R&D but will require a long time period owing to the size of the catchment and will require a large capital investment. (Abedini, M., Said, M. A. M., & Ahmad, F., 2012. Effectiveness of check dam to control soil erosion in a tropical catchment (The Ulu Kinta Basin). Catena, 97, 63-70.)
[32]Protection procedures will take long time but will help in removing the impact completely.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
WIND					
IIncrease in high wind events and wind speed in autumn and winter - **High**	Disturbance of migratory birds especially on the north-eastern shore in afternoons – may cause shifts of birds to more sheltered bays	Installation of devices to continuously monitor the change in wind patterns	**High**[33]	**High**[34]	**High**
	Erosion of shoreline on the north-eastern shore	Bunds can be constructed to reduce the erosion on the North-Eastern shoreline	**High**[35]	**Medium**[36]	**Medium**

[33]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J., 2018. Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450)

[34]It can only deal with the impact partially.

[35]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[36]It will indirectly avoid the impact and the extent will be partial

Photo credit: CarrotFilms.GIZ

Annex 4.4.1 - 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: CarrotFilms.GIZ

Annex 4.5 - 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, inhabits mainly Himalayan rivers in the foothills, Pong Dam

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) - **High**	Increased erosion in the catchment leads to increased sediment loads in the reservoir, altering the breeding ground for fish.	Conservation of remaining forest areas within the catchment	Medium[1]	Medium[2]	Medium
		Watershed management program with communities	High[3]	Medium[4]	Medium
		Protection of first- and second-order streams through bunding and check-dams	Medium[5]	High[6]	High
		Soil conservation measures. Creating a network of hydro met stations and silt traps to assess the extent of the problem	High[7]	Medium[8]	Medium
		Exploring more resilient aquatic plant species that provide adequate habitats for migratory birds (e.g., on the mounds)	High[9]	Medium[10]	Medium
		Piloting the growing of crops in drawdown areas for a win-win (to be assessed over time; could only continue under strict standards and controls - e.g., the use of agricultural chemicals)	High[11]	Medium[12]	Medium

[1]Conservation is feasible without additional R&D but will require a long time period owing to the size of the catchment. Studies supporting the action plan (Biao, Z., Wenhua, L., Gaodi, X., & Yu, X., 2010. Water conservation of forest ecosystem in Beijing and its value. Ecological economics, 69(7), 1416-1426.)

[2]The impact can only be partially avoided and the adaptation will take long time.

[3]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan. Study supporting this action plan: Moore, L., & Thornton, K. (1988). Lake and reservoir restoration guidance manual (No. PB-88-230719/XAB). North American Lake Management Society, Merrifield, VA (USA).

[4]It will deal with the impact partially.

[5]Protection is feasible without additional R&D but will require a long time period owing to the size of the catchment and will require a large capital investment (Abedini, M., Said, M. A. M., & Ahmad, F., 2012. Effectiveness of check dam to control soil erosion in a tropical catchment (The Ulu Kinta Basin). Catena, 97, 63-70.)

[6]Protection procedures will take long time but will help in removing the impact completely.

[7]Implementation is technically feasible without any additional R&D and can be implemented immediately (Brune, G. M., 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418.)

[8]Can only avoid the impact partially.

[9]Implementation is technically feasible without any additional R&D and can be implemented immediately.

[10]Can only avoid the impact partially.

[11]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Kunisue, T., Watanabe, M., Subramanian, A., Sethuraman, A., Titenko, A. M., Qui, V., & Tanabe, S., 2003. Accumulation features of persistent organochlorines in resident and migratory birds from Asia. Environmental pollution, 125(2), 157-172).

[12]Can only avoid the impact partially and might also impact the population living downstream.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Creating additional habitat diversity with the addition of perched wetland, mounds and depressions, within drawdown areas (also could be tested downstream of the reservoir)	High[13]	Medium[14]	Medium
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) – **Very High**	Increase temperature will lead to higher evapotranspiration and high water withdrawals will greatly undermine the fish species diversity and distribution in the Pong dam.	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.	High[15]	Medium[16]	Medium
		Covering the surface of water bodies with a fixed or floating cover considerably reduces evaporation losses	Medium[17]	High[18]	High
	Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species	Plant tall bushes or trees around the outside of the pond to shade the water.	High[19]	Medium[20]	Medium
	Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l	Increasing the contact of water with air using mechanical ways such as diffusers.	Medium[21]	High[22]	High

[13]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Hollander, F. A., Van Dyck, H., San Martin, G., & Titeux, N., 2011. Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PloS one, 6(9), e25703).
[14]Can only avoid the impact partially.
[15]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Oron, G. (1990). Economic considerations in wastewater treatment with duckweed for effluent and nitrogen renovation. Research Journal of the Water Pollution Control Federation, 692-696.)
[16]Can only avoid the impact partially.
[17]Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require large capital investment. (Lehmann, P., Aminzadeh, M., & Or, D., 2019. Evaporation suppression from water bodies using floating covers: laboratory studies of cover type, wind, and radiation effects. Water Resources Research, 55(6), 4839-4853.)
[18]Can remove the impact significantly and can be implemented in a short period of time.
[19]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Castelletti, A., Galelli, S., Restelli, M., & Soncini-Sessa, R., 2010. Tree-based reinforcement learning for optimal water reservoir operation. Water Resources Research, 46(9)).
[20]Can only avoid the impact partially and will take a long time for the trees to grow.
[21]Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Mobley, M. H., & Brock, W. G., 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234).
[22]Can remove the impact significantly.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
		Establishment of precise devices in the reservoir to continuously monitor DO levels.	High[23]	Medium[24]	Medium
		Assessing the impact of the reservoir DO level on the breeding characteristics of the Mahseer	Medium[25]	Medium[26]	Medium
EXTREME EVENTS					
Flood - High	The fish species richness is primarily driven by the quantum of water discharge in the rivers.	Construction of retention reservoir to control flooding	Medium[27]	High[28]	Medium
		Implementation of flood control management system for the pong reservoir (which includes (1) data collection, (2) observed data validation and processing, (3) reservoir forecasting, (4) flood control operation and (5) information inquiry)	High[29]	High[30]	High
		Implementation of flood control through the system of reservoirs	Medium[31]	High[32]	High
	Increasing turbidity and sediment in the reservoir from increased erosion will help predators	Reforestation, diversion dams and measures can be taken at the reservoir inflow	Medium[33]	Medium[34]	Medium

[23] It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J., 2018. Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450).

[24] It can only deal with the impact partially.

[25] Additional R&D will be required, and cannot be implemented immediately.

[26] It will indirectly avoid the impact and the extent will be partial.

[27] The implementation of the procedure to the reservoir of large size like Pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Patro, M., 2008. Influence of in-field retention reservoirs on soil outflow from a catchment. Annals of Warsaw University of Life Sciences-SGGW. Land Reclamation, 39).

[28] Can remove the impact significantly.

[29] Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K., 2004. Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267).

[30] Impact can be avoided completely and this adaptation will serve for a long period.

[31] This is an action research to assess the effectiveness of adaptation measures in the affected areas. The extent to this measure can be rolled out will be compromised by other interests concerned with maintaining water volume in the reservoir. The planting could be restricted to the drawdown areas. (Chang, L. C., Chang, F. J., & Hsu, H. C., 2010. Real-time reservoir operation for flood control using artificial intelligent techniques. International Journal of Nonlinear Sciences and Numerical Simulation, 11(11), 887-902).

[32] Impact can be avoided completely and this adaptation will serve for a long period.

[33] Additional R&D will be required, and cannot be implemented immediately. (Miller, J. R., Sinclair, J. T., & Walsh, D., 2015. Controls on suspended sediment concentrations and turbidity within a reforested, Southern Appalachian headwater basin. Water, 7(6), 3123-3148).

[34] It will indirectly avoid the impact and the extent will be partial

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
		Activities in the reservoirs themselves to remove sediment: dredging, mechanical digging, totally or partially emptying them	Medium[35]	High[36]	High
		Activities downstream from the reservoirs. Ecological flows.	Medium[37]	Low[38]	Medium
Drought - High	Algae and Vegetation will also get affected.	Installation of vertical curtains to reduce the nutrient loading in the reservoir	High[39]	High[40]	High
		Use of shading materials to reduce the evaporation losses from a specific section of the reservoir thereby reducing the impact on vegetation	Medium[41]	High[42]	High
		Feeding the fish during months of food shortage	High[43]	Medium[44]	High
	Lowẻ water level in the reservoir and lower soil moisture	Regulation of water level in the reservoir based on the impact on the fish	High[45]	Medium[46]	Medium
		Regulation of fishing during low water levels as fishing becomes easy and higher number of fishes are trapped in the nets	High[47]	High[48]	High

[35]Implementation of the procedure to the reservoir of large size like Pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Erftemeijer, P. L., Riegl, B., Hoeksema, B. W., & Todd, P. A., 2012. Environmental impacts of dredging and other sediment disturbances on corals: a review. Marine pollution bulletin, 64(9), 1737-1765).

[36]Can remove the impact significantly.

[37]Implementation will take long period of time and can affect the local communities.

[38]The extent of reduction in the problem will be very low.

[39]It is technically feasible with little R&D. Additionally, it is cost effective and can be implemented in short period of time. (Asaeda, T., Priyantha, D. N., Saitoh, S., & Gotoh, K., 1996. A new technique for controlling algal blooms in the withdrawal zone of reservoirs using vertical curtains. Ecological Engineering, 7(2), 95-104).

[40]Can remove the impact significantly.

[41]The implementation of the procedure to the reservoir of large size like Pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Alvarez, V. M., Baille, A., Martínez, J. M., & González-Real, M. M., 2006. Efficiency of shading materials in reducing evaporation from free water surfaces. Agricultural Water Management, 84(3), 229-239)

[42]Can remove the impact significantly.

[43]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[44]Can only remove the impact partially.

[45]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skill and institutional arrangements to support this action.

[46]Can only remove the impact partially.

[47]It is technically feasible with no additional R&D, can be implemented immediately and will require support of the local communities.

[48]Can significantly reduce the impact.

Annex 4.5.1 - 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: CarrotFilms.GIZ

Annex 4.6 - Adaptation Planning Matrix for Migratory bird habitats

ASSET NAME: MIGRATORY BIRD HABITATS

ASSET DESCRIPTION: The most important habitat is found at Nagrota Surian which has 50% more than another location marked on map. More generally it is the Northern shoreline, flat shallow areas that retain aquatic plants and rhizomes, mudflats with access to arable land for lapwings and geese.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) – **Very High**	Increased erosion in the catchment leads to increased sediment loads in the reservoir, smothering of aquatic plant habitat and shift of mudflat zones	Conservation of remaining forest areas within the catchment	Medium[1]	Medium[2]	Medium
		Watershed management program with communities	High[3]	Medium[4]	Medium
		Protection of first- and second-order streams through bunding and check-dams	Medium[5]	High[6]	High
		Soil conservation measures. Creating a network of hydro met stations and silt traps to assess the extent of the problem	High[7]	Medium[8]	Medium
		Exploring more resilient aquatic plant species that provide adequate habitats for migratory birds (e.g., on the mounds)	High[9]	Medium[10]	Medium
		Piloting the growing of crops in drawdown areas for a win-win (to be assessed over time; could only continue under strict standards and controls - e.g., the use of agricultural chemicals)	High[11]	Medium[12]	Medium

[1]Conservation is feasible without additional R&D but will require a long time period owing to the size of the catchment. Studies supporting the action plan (Biao, Z., Wenhua, L., Gaodi, X., & Yu, X. (2010). Water conservation of forest ecosystem in Beijing and its value. Ecological economics, 69(7), 1416-1426).

[2]The impact can only be partially avoided and the adaptation will take long time.

[3]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan. Study supporting the action plan (Moore, L., & Thornton, K. (1988). Lake and reservoir restoration guidance manual (No. PB-88-230719/XAB). North American Lake Management Society, Merrifield, VA (USA)).

[4]It will deal with the impact partially.

[5]Protection is feasible without additional R&D but will require a long time period owing to the size of the catchment and will require a large capital investment. (Abedini, M., Said, M. A. M., & Ahmad, F. (2012). Effectiveness of check dam to control soil erosion in a tropical catchment (The Ulu Kinta Basin). Catena, 97, 63-70).

[6]Protection procedures will take long time but will help in removing the impact completely.

[7]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M. (1953). Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418).

[8]Can only avoid the impact partially.

[9]Implementation is technically feasible without any additional R&D and can be implemented immediately.

[10]Can only avoid the impact partially.

[11]Implementation is technically feasible without any additional R&D and can be implemented immediately. (Kunisue, T., Watanabe, M., Subramanian, A., Sethuraman, A., Titenko, A. M., Qui, V. & Tanabe, S. (2003). Accumulation features of persistent organochlorines in resident and migratory birds from Asia. Environmental pollution, 125(2), 157-172).

[12]Can only avoid the impact partially and might also impact the population living downstream

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
		Creating additional habitat diversity with the addition of perched wetland, mounds and depressions, within drawdown areas (also could be tested downstream of the reservoir)	High[13]	Medium[14]	Medium
	Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in Terrace swamp. Regular violent releases could erode downstream wetland	Formulation of strict guidelines on discharge through the reservoir	High[15]	High[16]	High
		Field and modelling studies to formulate the guidelines on release through the reservoir	High[17]	High[18]	High
Decrease of rainfall during Winter (Jan-Feb) - **High**	Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out	Creating additional habitat diversity with the addition of perched wetland, mounds and depressions, within drawdown areas (also could be tested downstream of the reservoir)	High[19]	Medium[20]	Medium
		Digging in the specific locations to sustain the mudflat regions	Medium[21]	High[22]	High
	Shallow water area available for migratory birds feeding will be reduced or extend further into the reservoir	Formulation of the catchment management plan to reduce the interception losses	High[23]	High[24]	High
		Identification of areas more frequently used for breeding and conserving these areas	High[25]	High[26]	High

[13]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skill and institutional arrangements to support this action. (Hollander, F. A., Van Dyck, H., San Martin, G., & Titeux, N. (2011). Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PloS one, 6(9), e25703).

[14]Can only avoid the impact partially.

[15]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K. (2004). Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267).

[16]Impact can be avoided completely and this adaptation will serve for a long period.

[17]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up.

[18]Can remove the impact significantly.

[19]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Hollander, F. A., Van Dyck, H., San Martin, G., & Titeux, N. (2011). Maladaptive habitat selection of a migratory passerine bird in a human-modified landscape. PloS one, 6(9), e25703).

[20]Can only avoid the impact partially.

[21]Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment.

[22]Can remove the impact significantly.

[23]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K. (2004). Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267).

[24]Impact can be avoided completely and this adaptation will serve for a long period.

[25]It is technically feasible with little R&D. Additionally, it is cost effective and can be implemented in short period of time.

[26]Impact can be avoided completely and this adaptation can be applied immediately.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	Arable winter crops grown around the reservoir may be less productive	Irrigation schemes can be developed to reduce the impact of the reduction in rainfall	High[27]	Medium[28]	Medium
		Formulation of strict guidelines on discharge through the reservoir	High[29]	Medium[30]	Medium
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) – **Very High**	Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species	Use of shading materials to reduce the evaporation losses from a specific section of the reservoir thereby reducing the impact aquatic species	Low[31]	High[32]	Medium
	Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l	Increasing the contact of water with air using mechanical ways such as diffusers.	Low[33]	High[34]	Medium
		Establishment of precise devices in the reservoir to continuously monitor DO levels.	High[35]	High[36]	High
		Assessing the impact of reservoir DO level on the breeding characteristics of the Mahseer	Medium[37]	Medium[38]	Medium
	Increase in phytoplankton and associated zooplankton growth and cycles of death and decay	Installation of vertical curtains to reduce the nutrient loading in the reservoir	Medium[39]	Medium[40]	Medium

[27] It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.
[28] It will indirectly avoid the impact and the extent will be partial
[29] It is technically feasible, can be implemented immediately and is cost effective. Implementation will require support from the local communities
[30] It will partially reduce the impact
[31] Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Lehmann, P., Aminzadeh, M., & Or, D. (2019). Evaporation suppression from water bodies using floating covers: laboratory studies of cover type, wind, and radiation effects. Water Resources Research, 55(6), 4839-4853.)
[32] Can remove the impact significantly and can be implemented in a short period of time.
[33] Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Mobley, M. H., & Brock, W. G. (1995). Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234.)
[34] Can remove the impact significantly and can be implemented in a short period of time.
[35] It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J. (2018). Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450)
[36] It can only deal with the impact partially.
[37] Additional R&D will be required, and cannot be implemented immediately.
[38] It will indirectly avoid the impact and the extent will be partial.
[39] It is technically feasible with little R&D. Additionally, it is cost effective and can be implemented in short period of time. (Asaeda, T., Priyantha, D. N., Saitoh, S., & Gotoh, K. (1996). A new technique for controlling algal blooms in the withdrawal zone of reservoirs using vertical curtains. Ecological Engineering, 7(2), 95-104.)
[40] This would be implemented by FD using native plant species that are resilient. It could be built with existing budget and would require the establishment of plots of mixed species. The planting regime can also assist in erosion control within drawdown areas. The complexity institutional arrangement for the area will require effective coordination.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Algal blooms, possibly increase in blue-green algae Riparian vegetation flourishes	Installation of vertical curtains to reduce the nutrient loading in the reservoir	Medium[41]	Medium[42]	Medium
	Crops above reservoir tend not to grow so well unless irrigated	Development of irrigation schemes during the period of low flow	High[43]	Medium[44]	Medium
Increase of temperature during the cold season (Oct-May) - High	Continued plant and phytoplankton growth and zooplankton through winter	Management efforts using Nitrogen and phosphorous to limit the phytoplankton growth	High[45]	Medium[46]	Medium
	More food for dabbling and diving ducks	Irrigation schemes should be developed for the nearby area therefore even during the period of low flow enough food will be available for migratory birds	Medium[47]	Medium[48]	Medium
	Cold sensitive plants will flourish with shifts away from seasonal cold-adapted plants	An agriculture adaptation plan should be proposed to deal with the changing climate	High[49]	Medium[50]	Medium
EXTREME EVENTS					
Flood - High	Increase in sediment in the reservoir from increased erosion	Construction of retention reservoir to control flooding	Medium[51]	High[52]	High

[41]It is technically feasible with little R&D. Additionally, it is cost effective and can be implemented in short period of time. (Asaeda, T., Priyantha, D. N., Saitoh, S., & Gotoh, K. (1996). A new technique for controlling algal blooms in the withdrawal zone of reservoirs using vertical curtains. Ecological Engineering, 7(2), 95-104.)

[42]Can remove the impact significantly.

[43]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Dzialowski, A. R., Wang, S. H., Lim, N. C., Spotts, W. W., & Huggins, D. G. (2005). Nutrient limitation of phytoplankton growth in central plains reservoirs, USA. Journal of Plankton Research, 27(6), 587-595.)

[44]It can only deal with the impact partially.

[45]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[46]It will indirectly avoid the impact and the extent will be partial

[47]Additional R&D will be required, and cannot be implemented immediately.

[48]It will indirectly avoid the impact and the extent will be partial.

[49]It is technically feasible, can be implemented immediately and is cost effective. The implementation will require support from the local communities

[50]It will partially reduce the impact

[51]The implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require large capital investment. (Patro, M. (2008). Influence of in-field retention reservoirs on soil outflow from a catchment. Annals of Warsaw University of Life Sciences-SGGW. Land Reclamation, 39.)

[52]Can remove the impact significantly.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
		Implementation of flood control management system for the pong reservoir (which includes (1) data collection, (2) observed data validation and processing, (3) reservoir forecasting, (4) flood control operation and (5) information inquiry)	High[53]	High[54]	High
	Shifts of mudflat zones	Reforestation, diversion dams and measures can be taken at the reservoir inflow.	Medium[55]	Medium[56]	Medium
		Activities in the reservoirs themselves to remove sediment: dredging, mechanical digging, totally or partially emptying them	Medium[57]	High[58]	High
		Activities downstream from the reservoirs. Ecological flows.	Medium[59]	Low[60]	Medium
	Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp.	Implementation of flood control through a system of reservoirs	Medium[61]	High[62]	High
Wind – Very High	Disturbance of migratory birds especially on North-Eastern shore in afternoons – may cause shifts of birds to more sheltered bays	Installation of devices to continuously monitor the change in wind patterns	High[63]	High[64]	High
	Erosion of shoreline on North-Eastern shore	Bunds can be constructed to reduce the erosion on the North-Eastern shoreline	High[65]	Medium[66]	Medium

[53]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K. (2004). Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267.)
[54]Impact can be avoided completely and this adaptation will serve for a long period.
[55]Additional R&D will be required, and cannot be implemented immediately. (Miller, J. R., Sinclair, J. T., & Walsh, D. (2015). Controls on suspended sediment concentrations and turbidity within a reforested, Southern Appalachian headwater basin. Water, 7(6), 3123-3148.)
[56]It will indirectly avoid the impact and the extent will be partial.
[57]Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require large capital investment. (Erftemeijer, P. L., Riegl, B., Hoeksema, B. W., & Todd, P. A. (2012). Environmental impacts of dredging and other sediment disturbances on corals: a review. Marine pollution bulletin, 64(9), 1737-1765.)
[58]Can remove the impact significantly.
[59]Implementation will take long period of time and can affect the local communities.
[60]The extent of reduction in the problem will be very low.
[61]This is an action research to assess the effectiveness of adaptation measures in the affected areas. The extent to this measure can be rolled out will be compromised by other interests concerned with maintaining water volume in the reservoir. The planting could be restricted to the drawdown areas. (Chang, L. C., Chang, F. J., & Hsu, H. C. (2010). Real-time reservoir operation for flood control using artificial intelligent techniques. International Journal of Nonlinear Sciences and Numerical Simulation, 11(11), 887-902.)
[62]Impact can be avoided completely and this adaptation will serve for a long period.
[63]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J. (2018). Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450)
[64]It can only deal with the impact partially.
[65]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.
[66]It will indirectly avoid the impact and the extent will be partial

Annex 4.6.1 - Scoring of feasibility and effectiveness for prioritising adaptation options

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

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Annex 4.7 - Adaptation Planning Matrix for the Pong Reservoir

ASSET NAME: RESERVOIR

ASSET DESCRIPTION: Open deep water, Shallow water in drawdown, Dry sandbanks with little or no vegetation, Waterside vegetation and swamps below the out-fall from the dam.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Increase of rainfall during Monsoon (Jun-Sep) – **Very High**	Increased areal water extent will lead to disturbances in the ecosystem through changes in water quality, turbidity, dissolved oxygen, surface water temperature and depth profiles of the aerobic layer.	Exploring more resilient and adaptive species that are capable to withstand these disturbances.	High[1]	Medium[2]	Medium
		Installation of devices to assess water quality, turbidity, dissolved oxygen, surface water temperature etc.	High[3]	Medium[4]	Medium
	Increased erosion in the catchment leads to increased sediment loads in the reservoir.	Conservation of remaining forest areas within the catchment	Medium[5]	Medium[6]	Medium
		Watershed management program with communities	High[7]	Medium[8]	Medium
		Piloting the growing of crops in drawdown areas for a win-win (to be assessed over time; could only continue under strict standards and controls - e.g., the use of agricultural chemicals)	High[9]	Medium[10]	Medium
	Requires increased releases of water from the reservoir, which may increase the frequency of downstream flooding in the Terrace swamp.	Construction of retention reservoir to control flooding	Medium[11]	High[12]	High

[1]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Moritz, C., & Agudo, R., 2013. The future of species under climate change: resilience or decline?. Science, 341(6145), 504-508.).
[2]Can only avoid the impact partially.
[3]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Mizuno, M., & Hirose, T., 2009. Instrumentation and monitoring of dams and reservoirs. Water Storage Transp. Distrib, 1, 1-8.)
[4]Can only avoid the impact partially.
[5]Conservation is feasible without additional R&D but will require a long time period owing to the size of the catchment. Studies support the action plan. (Biao, Z., Wenhua, L., Gaodi, X., & Yu, X., 2010. Water conservation of forest ecosystem in Beijing and its value. Ecological economics, 69(7), 1416-1426)
[6]The impact can only be partially avoided and the adaptation will take long time.
[7]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan. Study supporting the action plan (Moore, L., & Thornton, K., 1988. Lake and reservoir restoration guidance manual (No. PB-88-230719/XAB). North American Lake Management Society, Merrifield, VA, USA).
[8]It will deal with the impact partially.
[9]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Kunisue, T., Watanabe, M., Subramanian, A., Sethuraman, A., Titenko, A. M., Qui, V., & Tanabe, S., 2003. Accumulation features of persistent organochlorines in resident and migratory birds from Asia. Environmental pollution, 125(2), 157-172).
[10]Can only avoid the impact partially and might also impact the population living downstream.
[11]The implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, the implementation will require a large capital investment. (Patro, M., 2008. Influence of in-field retention reservoirs on soil outflow from a catchment. Annals of Warsaw University of Life Sciences-SGGW. Land Reclamation, 39).
[12]Can remove the impact significantly.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during Winter (Jan-Feb) - **High**	Drawn down exposes sandbanks, which can be potential nesting sites.	Prohibiting nesting of the local inhabitants in the nearby areas of the reservoir.	**High[13]**	**Medium[14]**	**Medium**
	Mudflat zone and aquatic vegetation will be more rapidly exposed and dry out	Implementation of flood control management system for the pong reservoir (which includes (1) data collection, (2) observed data validation and processing, (3) reservoir forecasting, (4) flood control operation and (5) information inquiry)	**High[15]**	**High[16]**	**High**
TEMPERATURE					
Increase of temperature during the hot season/ Monsoon (Jun-Sep) - **Very High**	Surface water temperature increases during summer, possibly beyond threshold limits for some aquatic species	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.	**High[17]**	**Medium[18]**	**Medium**
		Exploring more resilient and adaptive aquatic species that are capable to withstand these disturbances	**High[19]**	**Medium[20]**	**Medium**
	Riparian and aquatic vegetation flourishes	Plant tall bushes or trees around the outside of the pond to shade the water.	**High[21]**	**Medium[22]**	**Medium**

[13]It is technically feasible with relatively less additional R&D, implementation will take less time, expected to be cost effective and involvement of local communities will enhance the effectiveness of the plan.

[14]It will deal with the impact partially.

[15]Technically feasible with no additional R&D, data procurement for the location is easy and the plan can be implemented easily and capacity of the community can be build up. (Böhm, H. R., Haupter, B., Heiland, P., & Dapp, K., 2004. Implementation of flood risk management measures into spatial plans and policies. River research and applications, 20(3), 255-267).

[16]Impact can be avoided completely and this adaptation will serve for a long period.

[17]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Oron, G., 1990. Economic considerations in wastewater treatment with duckweed for effluent and nitrogen renovation. Research Journal of the Water Pollution Control Federation, 692-696).

[18]Can only avoid the impact partially.

[19]The implementation is technically feasible without any additional R&D and can be implemented immediately (Moritz, C., & Agudo, R., 2013. The future of species under climate change: resilience or decline?. Science, 341(6145), 504-508).

[20]Can only avoid the impact partially.

[21]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Castelletti, A., Galelli, S., Restelli, M., & Soncini-Sessa, R., 2010. Tree-based reinforcement learning for optimal water reservoir operation. Water Resources Research, 46(9)).

[22]Can only avoid the impact partially and will take a long time for the trees to grow.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
	Dissolved oxygen in water decreases possibly below the threshold levels of 5 mg/l	Increasing the contact of water with air using mechanical ways such as diffusers.	Medium[23]	High[24]	High
		Establishment of precise devices in the reservoir to continuously monitor DO levels.	High[25]	Medium[26]	Medium
	Significant increase in evaporation losses.	Covering the surface of water bodies with a fixed or floating cover considerably reduces evaporation losses	Medium[27]	High[28]	High
EXTREME EVENTS					
Flood - **High**	Flood should not have a significant impact on the reservoir as it is an inundated area and the water level is regulated.	Construction of retention reservoir to control flooding	Medium[29]	High[30]	Medium
		Implementation of flood control through a system of reservoirs	Medium[31]	High[32]	High
	Areal water extent increase at an intense rate led to disturbances and others.	Reforestation, diversion dams and measures can be taken at the reservoir inflow.	Medium[33]	Medium[34]	Medium

[23]The implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Mobley, M. H., & Brock, W. G., 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234).

[24]Can remove the impact significantly

[25]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action. (Elkiran, G., Nourani, V., Abba, S. I., & Abdullahi, J., 2018. Artificial intelligence-based approaches for multi-station modelling of dissolve oxygen in river. Global Journal of Environmental Science and Management, 4(4), 439-450).

[26]It can only deal with the impact partially.

[27]Implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Lehmann, P., Aminzadeh, M., & Or, D., 2019. Evaporation suppression from water bodies using floating covers: laboratory studies of cover type, wind, and radiation effects. Water Resources Research, 55(6), 4839-4853).

[28]Can remove the impact significantly and can be implemented in a short period of time.

[29]The implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Patro, M., 2008. Influence of in-field retention reservoirs on soil outflow from a catchment. Annals of Warsaw University of Life Sciences-SGGW. Land Reclamation, 39).

[30]Can remove the impact significantly.

[31]This is an action research to assess the effectiveness of adaptation measures in the affected areas. The extent to this measure can be rolled out will be compromised by other interests concerned with maintaining water volume in the reservoir. The planting could be restricted to the drawdown areas. (Chang, L. C., Chang, F. J., & Hsu, H. C., 2010. Real-time reservoir operation for flood control using artificial intelligent techniques. International Journal of Nonlinear Sciences and Numerical Simulation, 11(11), 887-902).

[32]Impact can be avoided completely and this adaptation will serve for a long period.

[33]Additional R&D will be required, and cannot be implemented immediately. (Miller, J. R., Sinclair, J. T., & Walsh, D., 2015. Controls on suspended sediment concentrations and turbidity within a reforested, Southern Appalachian headwater basin. Water, 7(6), 3123-3148).

[34]It will indirectly avoid the impact and the extent will be partial.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	Increase in sediment in the reservoir by erosion	Soil conservation measures. Creating a network of hydro met stations and silt traps to assess the extent of the problem	High[35]	Medium[36]	Medium
	Decrease in D.O and water quality due to organic matter and sediment run-off in flood water	Increasing the contact of water with air using mechanical ways such as diffusers.	Medium[37]	High[38]	High
Drought - **High**	Increased demand for irrigation water from the reservoir.	Irrigation schemes can be developed to reduce the impact of drought	High[39]	Medium[40]	Medium
		Cropping pattern change during years of expected drought	High[41]	Medium[42]	Medium
	Lower water level in the reservoir.	Regulation of water level in the reservoir based on the possible impact of drought	High[43]	Medium[44]	Medium
	Potential for algal blooms and reduce water quality	Installation of vertical curtains to reduce the nutrient loading in the reservoir	Medium[45]	Medium[46]	Medium
Wind - **High**	Erosion of shoreline on the north-eastern shore	Bunds can be constructed to reduce the erosion on the North-Eastern shoreline	High[47]	Medium[48]	Medium
	Greater mixing of reservoir waters, with potential for inversion of anaerobic layers, leading to fish kills	Continuous monitoring of fish health in the reservoir and documentation of events where a large number of fish die during a period.	High[49]	Medium[50]	Medium

[35]The implementation is technically feasible without any additional R&D and can be implemented immediately. (Brune, G. M., 1953. Trap efficiency of reservoirs. Eos, Transactions American Geophysical Union, 34(3), 407-418).

[36]Can only avoid the impact partially.

[37]The implementation of the procedure to the reservoir of large size like pong will be tedious and will require additional R&D. In addition to this, implementation will require a large capital investment. (Mobley, M. H., & Brock, W. G., 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reservoir Management, 11(3), 231-234).

[38]Can remove the impact significantly

[39]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[40]It will indirectly avoid the impact and the extent will be partial

[41]It is technically feasible, can be implemented immediately and is cost effective. Implementation will require support from the local communities

[42]It will partially reduce the impact

[43]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[44]Can only remove the impact partially.

[45]It is technically feasible with little R&D. Additionally, it is cost effective and can be implemented in short period of time. (Asaeda, T., Priyantha, D. N., Saitoh, S., & Gotoh, K., 1996. A new technique for controlling algal blooms in the withdrawal zone of reservoirs using vertical curtains. Ecological Engineering, 7(2), 95-104).

[46]Can remove the impact significantly.

[47]It is technically feasible, can be implemented immediately and is cost effective. Government has significant skills and institutional arrangements to support this action.

[48]It will indirectly avoid the impact and the extent will be partial.

[49]The implementation is technically feasible without any additional R&D and can be implemented immediately.

[50]Can only avoid the impact partially.

Annex 4.7.1 - 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

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