HYDROLOGICAL AND CLIMATE RISK MODELLING FOR PONG DAM LAKE, HIMACHAL PRADESH

AN ASSESSMENT FOR INTEGRATED MANAGEMENT

हिमाचल प्रदेश सरकार

INTERNATIONAL CLIMATE INITIATIVE

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

of the Federal Republic of Germany

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Address
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Indo-German Biodiversity Programme (IGBP),
GIZ-India, A-2/18, Safdarjung Enclave, New Delhi - 110029, India

E-Mail: biodiv.india@giz.de
Web: www.giz.de & www.indo-germanbiodiversity.com

Programme/project description
Wetlands Management for Biodiversity and Climate Protection
Indo-German Biodiversity Programme

Implementing Partners
Ministry of Environment, Forest and Climate Change
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Wetlands International South Asia, New Delhi

Responsible
Ravindra Singh, Director, Indo-German Biodiversity Programme, GIZ
Geetha Nayak, Project Manager, Wetlands Management for Biodiversity and Climate Protection, GIZ

Prepared by
INRM Consultants Pvt. Ltd.

Suggested Citation
INRM Consultants Pvt. Ltd. (2023). Hydrological and Climate Risk Modelling for Pong Dam Lake, Himachal Pradesh-
An Assessment for Integrated Management. Prepared for GIZ.

Authors
A.K. Gosain, Sandhya Rao, Puja Singh and Ankush Mahajan

Technical Contributions
Kunal Bharat, Avantika Bhaskar, Shambhavi Krishna (GIZ)
Ritesh Kumar, Harsh Ganapathi (Wetlands International South Asia)
Also acknowledging contributions from Debojyoti Mukherjee, Ridhi Saluja, Chaitanya Raj and Sakshi Saini.

Photo credits/sources
GIZ/Kunal Bharat (cover page photo) and as specified against images.

Page Layout and design
Tryphena Kirubakaran
E-Mail: tryphenaa@gmail.com

Disclaimer
The views expressed in the report are purely those of the authors and may not in any circumstances be regarded as stating an official position of the Ministry of Environment, Forest and Climate Change (MoEFCC) or GIZ. The designation of geographical entities in the report, and presentation of material, do not imply the expression of any opinion whatsoever on the part of MoEFCC or GIZ concerning the legal status of any country, territory, or area or its authorities or concerning the delimitation of its frontiers or boundaries.

This project is part of the International Climate Initiative (IKI).

On behalf of
German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

New Delhi, 2023

HYDROLOGICAL AND CLIMATE RISK MODELLING FOR PONG DAM LAKE, HIMACHAL PRADESH

AN ASSESSMENT FOR INTEGRATED MANAGEMENT

Table of Contents

List of Figures

List of Tables

Photo credit: CarrotFilms.GIZ

Abbreviations

AR5	FIFTH ASSESSMENT REPORT
BBMB	BHAKRA BEAS MANAGEMENT BOARD
BIS	BUREAU OF INDIAN STANDARDS
CSDI	COLD SPELL DURATION INDICATOR
CWC	CENTRAL WATER COMMISSION
DEM	DIGITAL ELEVATION MODEL
DN	DIGITAL NUMBER
DSL	DEAD STORAGE LEVEL
EC	END CENTURY
FAO	FOOD AND AGRICULTURE ORGANIZATION
FCC	FALSE COLOUR COMPOSITE
FSL	FULL STORAGE LEVEL
GIS	GEOGRAPHIC INFORMATION SYSTEM
ha	HECTARES
HRU	HYDROLOGICAL RESPONSE UNIT
IMD	INDIAN METEOROLOGICAL DEPARTMENT
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
Landsat	EARTH-OBSERVING SATELLITE MISSIONS JOINTLY MANAGED BY NASA AND THE USGS
LULC	LAND USE AND LAND COVER
m	METERS
MC	MID-CENTURY
Mha	MILLION HECTARES
Mm^3	MILLION CUBIC METERS
Mcm/yr	MILLION CUBIC METERS PER YEAR
Msl	MEAN SEA LEVEL
MUSLE	MODIFIED UNIVERSAL SOIL LOSS EQUATION
NBSSLUP	NATIONAL BUREAU OF SOIL SURVEY AND LAND USE PLANNING
NRSC	NATIONAL REMOTE SENSING CENTRE
NRSA	NATIONAL REMOTE SENSING AGENCY
NDWI	NORMALIZED DIFFERENCE WATER INDEX
NIR	NEAR-INFRARED
SWAT	SOIL AND WATER ASSESSMENT TOOL
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
RCM	REGIONAL CLIMATE MODEL
RS	REMOTE SENSING
WRIS	WATER RESOURCES INFORMATION SYSTEM
WSDI	WARM SPELL DURATION INDICATOR

EXECUTIVE SUMMARY

Population growth, urbanization and changing land use land cover practices are responsible for the loss of ecosystem services of wetlands around the world. The land use land cover change maps of the period between 2001 and 2020 derived from remote sensing imageries showed that the Pong Dam lake is severely affected due to anthropogenic pressure, posing risks on habitat within its catchment area. Land use study of the area suggests that the agricultural area has increased by 16.7%. Barren land has decreased between the years 2001 and 2020 by 16.4%. The foregoing data indicates a rapid conversion of waste and barren land for agricultural purpose in this area. It is also observed that the urban area has also increased significantly over two decades.

The rate of sedimentation in the wetland is around 24.4 Mcm/yr (which falls under moderate/medium range as per *Handbook for Assessing and Managing Reservoir Sedimentation* published by CWC in 2018), which is likely to increase in the near future due to large-scale unregulated or unplanned development in the area. The climate change scenario will generate more flash flood and flood-like events in the future, which will cause more erosion in the area. This erosion will result in additional sedimentation.

Water resources in India are under heavy stress due to increased water demand and limited availability of water. Sustainable water management of river basins is essential to ensure a long-term stable and flexible water supply to meet the crop water demands as well as growing municipal and industrial water demands in the respective basins. To establish the water availability in Pong Dam lake, water balance of this catchment has been analysed for the existing climate change and land use change scenarios. It is evident from the results that in the RCP 4.5, due to increase in rainfall by 5% in Pong catchment in the middle of this century, there will be an increase of 9.7% in surface run-off, and at the end of this century, there will be an increase of 11% in rainfall and the surface run-off will increase by 12%. In the RCP 8.5, the surface run-off will increase by 25% to 30%,but the increase in rainfall and surface run-off will not be evenly distributed. One day maximum rainfall events shall increase in both RCP 4.5 and RCP 8.5, resulting in more flood-like events in future.

In the future climate change scenario, RCP 8.5 will impact the basin rainfall as well as temperature (both maximum and minimum). It is observed from the analysis of the climate change projections that there will be more warm spells in the future in the coming century. It is evident from the hydrological model output that increase in rainfall will not help in providing adequate water to the rainfed crops,[1] as the number of rainy days will decrease. The increased temperature is not favourable for the growth of traditional crops and therefore a shift in cropping pattern and timing will be required. In addition, new varieties of crops, which can sustain the increasing temperature in the region will have to be introduced. It is also evident from climate data analysis that rainfall intensity has increased, whereas the number of rainy days has reduced, causing intense rainfall and resulting in more flood-like events. Alteration in temperature will impact the growth cycle of the plants. This shift and increase in temperature and warm spells call for a major shift in the agricultural practices of the entire Pong Dam lake catchment area. Not only agricultural practices, but it will also impact the humans, livestock of the area and adaptation to these changes will require a change in lifestyle. Migratory birds will also get impacted due to warmer temperature.

This degradation is expected to deteriorate further under the current climate change scenarios. To reduce further adverse impacts in this wetland, agricultural practices should be minimized in the area and agroforestry practices should be encouraged to maintain the health and ecology of the wetland.

[1] Rainfed crops are grown where irrigation is not provided and crop water requirement is met by rainfall. All the monsoon crops are normally rainfed, and additional water is required in non-monsoon months, which is supplemented by irrigation from reaches, groundwater or reservoirs

INTRODUCTION

Wetlands are critical natural resources since they perform a range of environmental functions and provide numerous socio-economic benefits to local communities and a wider population. In recent years, human activities are exerting pressure on the environment with consequences such as global climate change, disruption of the hydrological cycle and impact on water catchments. In addition, due to increasing demand for energy and food, water-intensive activities are increasing with population growth. An improved knowledge of water resources and related risks is essential in order to optimize the allocation of water for various uses. Many wetlands throughout India have come under extreme pressure as socio-economic change and population pressure have stimulated a need for more agriculturally productive land. Although wetland drainage and cultivation can make a key contribution to food and livelihood security in the short term, there are concerns over the sustainability of this utilization and the maintenance of wetland benefits in the long term. Many kinds of wetland ecosystems are found within India. The characteristics and functions of any given wetland are determined by climate, hydrology and substrate, as well as by position and dominance in the landscape.

Wetlands are the most productive ecosystem on earth and have been recognized globally for their vital role in sustaining a wide array of biodiversity; they also provide goods and services to the society. They support millions of people– not only the local population living in their fringes but also the population outside the wetlands area. The Ministry of Environment, Forests and Climate Change of the Government of India, has declared at least 37 wetlands of national importance in the country. Out of these, three wetlands, Pong Dam lake, Renuka Wetland and Chandertal, are situated in Himachal Pradesh. The state of Himachal Pradesh has 27 natural wetlands covering an area of 15 km^2 and 5 man-made wetlands covering an area of 712 km^2 (Pathania & Gurrala, 2017). The Pong Dam lake in Kangra district of Himachal Pradesh is one of the largest man-made wetlands of North India. The catchment area of the wetland is 12,561 km^2. This reservoir covers an area of 245.29 km^2 with a wetland portion of 156.62 km^2 (Pathania & Gurrala, 2017). Pong Dam lake was declared a Ramsar Site on account of its rich waterfowl diversity and sustainable use of the wetland.

STUDY AREA

The Beas river, on which Pong Dam lake and its reservoir are located, is one of the five major rivers of the Indus basin, India. The reservoir, located at longitude 76° E and latitude 32° N, drains a catchment area of 12,561 km^2, out of which the area with permanent snow catchment is 780 km^2 (Jain et al., 2007). Active storage capacity of the reservoir is 7290 Mm^3. Water stored in Pong Dam lake is primarily used for meeting irrigation water demands: 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 irrigated fields. The major crops cultivated in the entire catchment are rice, wheat, maize and cotton. Monsoon rainfall between June and September is a major source of water inflow into the reservoir, apart from snow and glacier melt. Snow and glacier melt run-off in Beas catchment was 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 lake).

Pong Dam lake wetland located in the Kangra district of Himachal Pradesh intercepts the Trans-Himalayan flyway. This wetland was incorporated in the List of Wetlands of International Importance under the Ramsar Convention in the year 2002 based on the immense diversity of waterfowl supported by it. The migratory waterfowl species use the wetland as a transitory habitat during their winter migration along the Central Asian Flyway. The birds remain confined to the lake until mid-April, which is the breeding season for them (Dhadwal, 2011). The present study investigates wetland dynamics through an analysis of land use land cover using geoinformatics technology. The aim of this study is to conduct hydrological and climate modelling to evaluate the risk associated with ecological functioning of the Pong Dam lake of Himachal Pradesh, India. Figure 1 shows the Pong Dam lake catchment area where 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. The total length of the reservoir is 41.8 km, with a widest stretch of 19.0 km. Figure 2 shows the streams joining the Pong Dam lake.

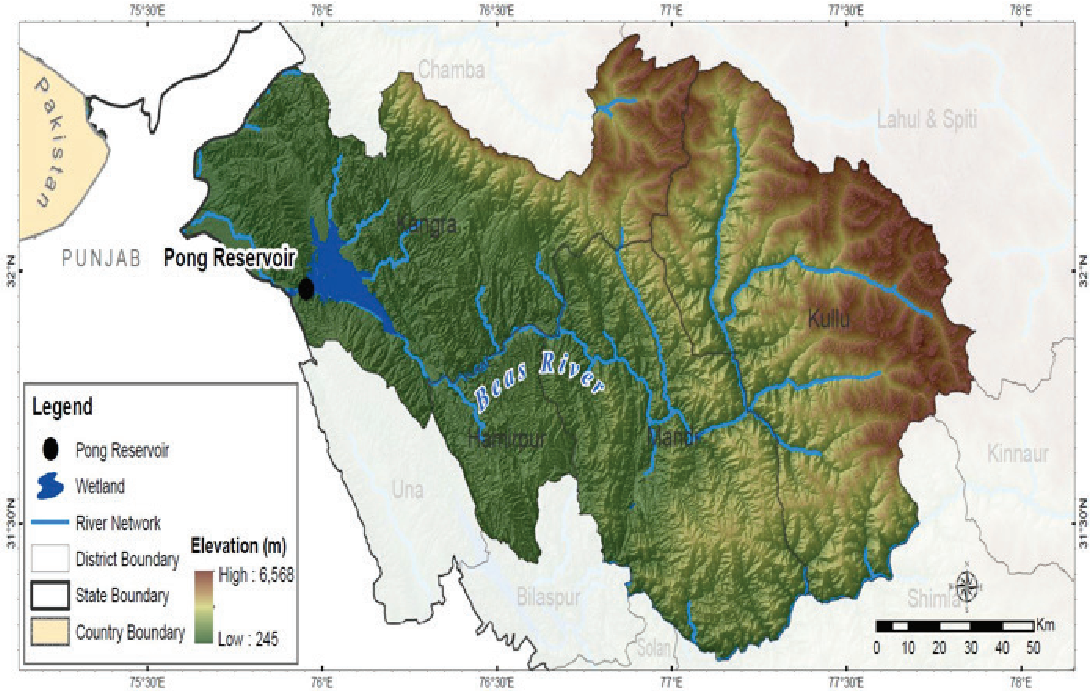


Figure 1 Pong Dam lake Catchment Area
(Source: INRM)

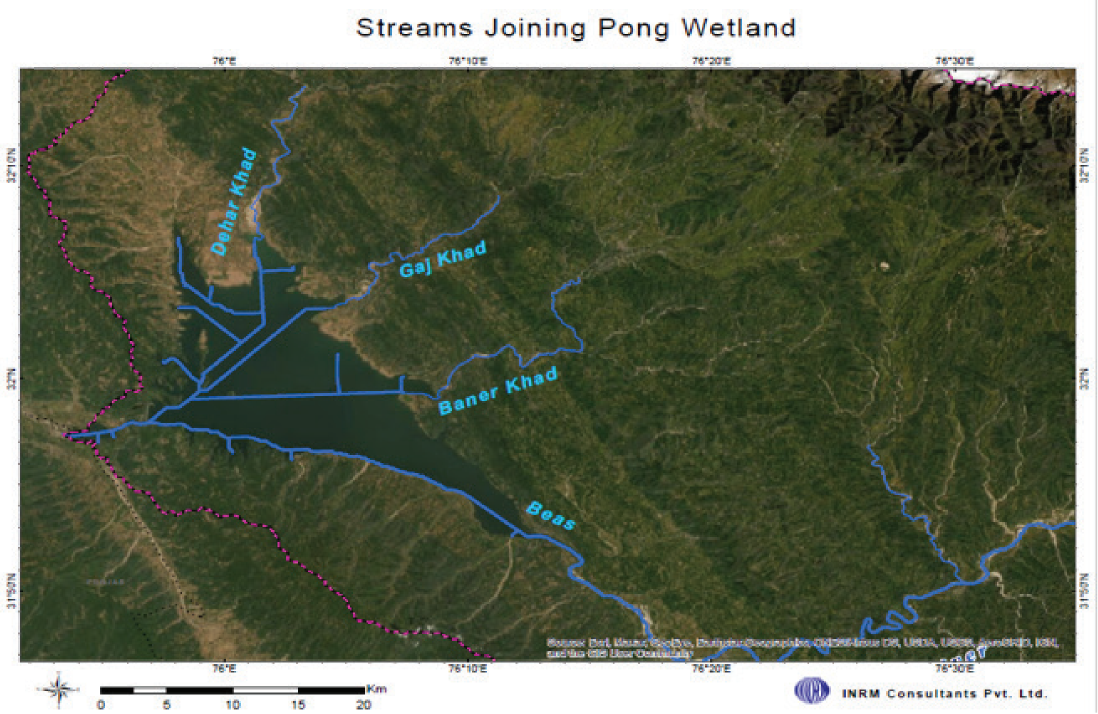


Figure 2 *Streams joining the Pong Dam lake*
(Source: INRM)

The Pong dam wetland, also called the Maharana Pratap Sagar reservoir, was constructed as an earthen dam at a place called Pong across River Beas. It is the largest man-made wetland at an altitude between 335 and 435 m msl. The area varies seasonally, and the water level recedes during summers to about 384 m msl(see table below).

Name/Season	Pong Dam Lake Area (km^2)	Ramsar Wetland Area (km^2)
Non-Monsoon	240	156.62
Monsoon	450	156.62

Outflows are the highest in July and the lowest in February, ranging from 8215 to 15,334 Mm^3. The reservoir has a number of seasonal, rainfed streams, locally known as ‘Khads’, the important ones being Baner, Gaj and Dehar. With the rise in level of the reservoir, the water extends to all these Khads, thereby forming a number of bays/lagoon-like areas, of which Dehar is the biggest part. These Khads carry nominal discharge (almost zero) into the reservoir during the dry season of March to June and October to December, but bring in appreciable discharge during monsoon and winter rains.

The wetland has been divided into three zones to prioritize conservation efforts. The wetland was listed as a site of national importance in 1994 and incorporated in the List of Wetlands of International Importance under the Ramsar Convention in 2002. It is the first major wetland offering a transitory resting reserve for migratory water birds coming from the Trans-Himalayan zone (Dhadwal, 2011). The Summer Bird Census in 2015 revealed that the Pong Dam lake is home to about 169 species of birds, 18 species of snakes, 90 species of butterflies, 24 mammal species (Malik, 2017 & Sharief et al., 2018). According to the latest report made by Wildlife officials in 2020, the number of bird species has gone up marginally compared to that in the 2018 census.

METHODOLOGY

The study is based on both primary and secondary data sources as well as information generated using hydrological modelling. Primary data have been collected through the Bhakra Beas Management Board website (BBMB) and online interaction with various stakeholders. Secondary data have been collected from various government papers, reports and articles. Gaps were substantiated with the help of newspaper reports as well.

HYDROLOGICAL MODELLING

A distributed hydrological model is often needed to analyse spatially variable hydrological behaviour. Mountainous catchments are of vital importance for freshwater supplies, and need proper setting up of a model. Due to the high elevation, snow is a dominant component of the hydrological cycle in Pong Dam lake catchment, having a decisive impact on hydrology-related issues including water supply, erosion, hydropower management and flood control (Cunderlik & Ouarda, 2009; Pradhanang et al., 2011; Rahman et al., 2013; Zampieri et al., 2013). Therefore, an accurate description of snow processes is of primary importance for hydrological research and water use in Himalayan catchments.

Proper water management is the only option that compresses the gap between the demand and supply. Sustainable water management of a river basin is essential to maintain stability and flexibility in water supply to meet the crop water and growing municipal and industrial water demands (Ximing Cai, 2001). Water resource structures need appropriate planning to ensure fulfilment of the goals of water management.

SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998; Neitsch et al., 2002) is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the hydrological response of ungauged catchments to natural inputs as well as man-made interventions. The SWAT model can analyse water quantity, water quality, water balance estimation and sediment yields.

SWAT is a long term, continuous time distributed hydrological model that operates on a daily time step. It is considered to be a versatile tool for watershed assessment. It can simulate many processes within the basin, including rainfall run-off and plant growth processes. This model comprises many components, including hydrology, climate, soils, land management, plant growth, pesticides and nutrients. It is also widely used and has a high efficiency for simulating and assessing hydrological processes under changing environments. The model partitions a watershed into sub-watersheds and contains input information that includes climate, hydrological response units (HRUs), soil types and their properties, land use type, ponds/wetlands, groundwater, and the main channel draining the sub-basin. In each HRU, the homogeneous flow can be simulated, and the outflow of each unit can be calculated. The ultimate result of the entire watershed can then be derived from the outlet of each sub-basin. The Pong Dam lake catchment area is shown in Figure 1. The processes of the SWAT model are depicted in Figure 3.

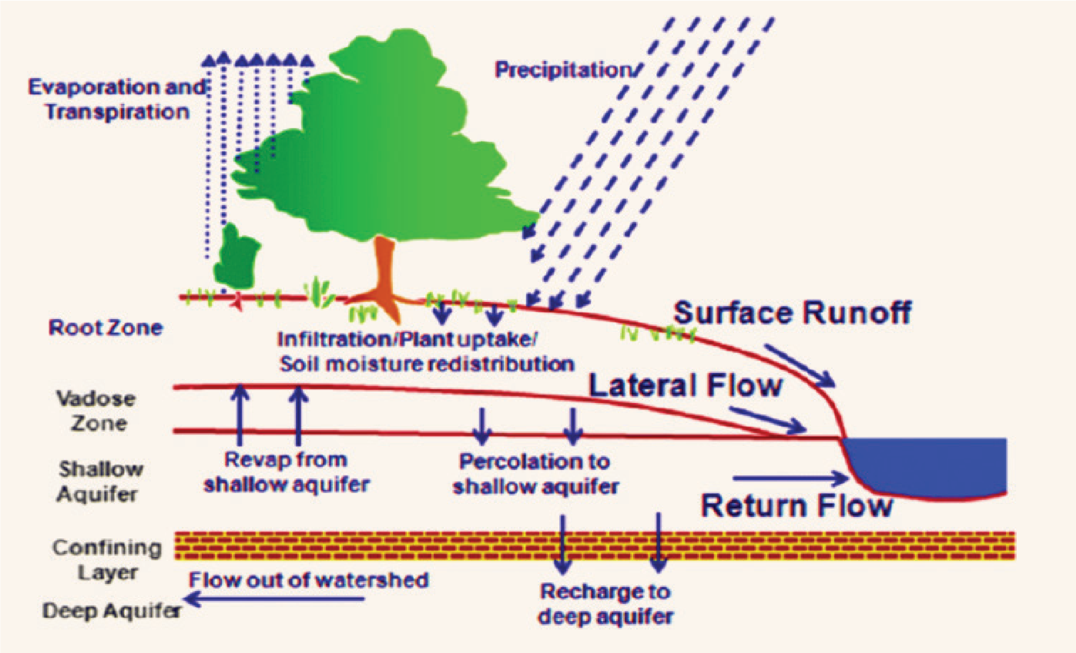


Figure 3 *SWAT Modelling Processes*
(Source: SWAT model website)

The SWAT model is designed to predict the impact of land management practices on water, sediment and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail by allowing the watershed to be divided into a large number of sub-watersheds. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides and land.

The major advantage of the SWAT model is that, unlike other conventional conceptual simulation models, it does not require much calibration and therefore can be used on ungauged watersheds (in fact the usual situation). The SWAT calibrated model can be used for generating various scenarios to quantify the natural flow regime, climate change impact, land use and land cover (LULC) impact, sedimentation rate, and water quality status of the river and wetland.

HYDROLOGICAL MODELLING INPUT DATASET FOR PONG DAM CATCHMENT

The resolution of input data has a direct link with the modelling resolution in distributed hydrological modelling, since the model's resolution is often set equal to or finer than the input data. Creating the input files in GIS compatible framework for integrated hydrological models requires GIS processing of raster and vector datasets from various sources. Developing stream network topology that is consistent with the model grid scale digital elevation model (DEM) is important. Precipitation and temperature are often the most important input data in hydrological models when simulating streamflow at high altitude.

The high resolution i.e. 0.25° x 0.25° latitude and longitude, daily gridded rainfall dataset and 1.0° x 1.0° daily gridded temperature datasets of 68 years (1951–2018) provided by the Indian Meteorological Department (IMD) have been used for Pong Dam lake catchment modelling. FAO/NBSSLUP soil data have been used for hydrological modelling. A 30-m resolution DEM has been used for delineation purpose. NRSA land use has been used for initial setting up of the hydrological model. The basic input parameters for SWAT are shown in Figure 4. The SWAT model is generally applied in high-altitude catchments using a unique set of snow parameters for the entire basin, and calibration is based on discharge data. Six interventions (projects) were implemented in the entire catchment. The model has been validated at seven gauge locations.

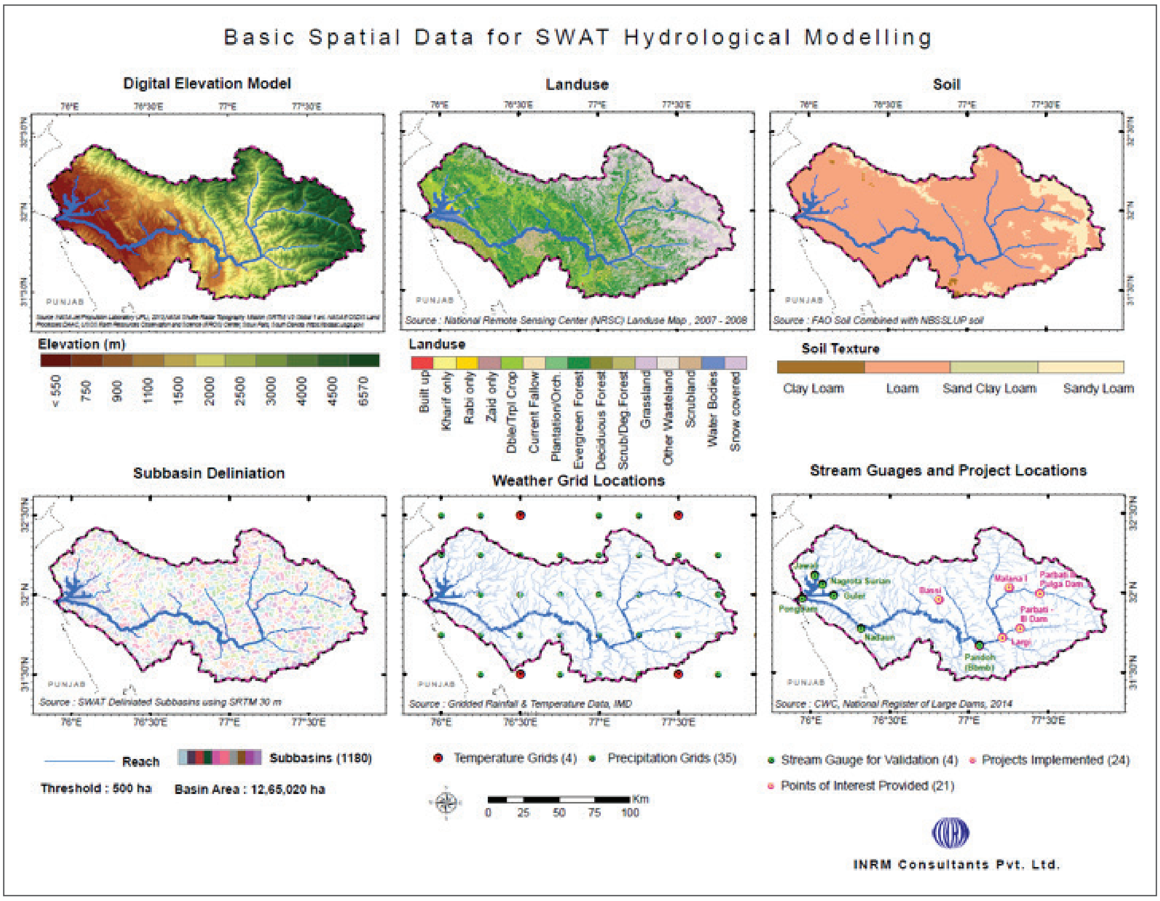


Figure 4 *Pong Dam lake Delineation and SWAT Hydrological Modelling Parameters (Source: INRM)*

HYDROLOGICAL MODELLING UNDER THE PRESENT SCENARIO

A Soil and Water Assessment Tool (SWAT) model was setup for hydrological modelling of the area. Hydrological modelling can provide a number of valuable results; at the same time it is important to focus on limitations and constraints involved in this process, primarily relating to input data, e.g. spatial resolution of rainfall and the quality of DEM, land use, soil and interventions. Precipitation, evapotranspiration, soil moisture and snow cover climatology are important for the basin hydrology (e.g. by impacting run-off and streamflow) and for the current and future utilization potential of water resources. Information on these parameters is therefore important for assessing the available water supply at basin scale. Such data are also extremely valuable for the calibration and validation of hydrological simulation models. If data like reservoir release and characteristics are absent, it is important to fill the data gap.

The Pong Dam lake principally provides irrigation water, although prior to its diversion to irrigation, the released water first passes through turbines for generating electricity (Jain et al., 2007). The current study focuses on the irrigation function of the reservoir. The reservoir inflow is highly influenced by both the monsoon rainfall and the melting glacier and seasonal snow from the Himalayas; consequently, its ability to satisfactorily perform its functions is susceptible to possible climate change disturbances in these climatic attributes. For a system that is inextricably linked to the socio-economic well-being of the region (Jain et al., 2007), any significant deterioration in performance or ability to meet the irrigation water demand will have far-reaching consequences. Therefore, it is important to carry out a systematic assessment of the performance of the reservoir considering climate change and to use the outcome to potentially inform the development of appropriate solutions.

After model setup, first-cut model outputs are used to visualize the flow pattern of the catchment. At present, the model is calibrated at seven locations, viz; Jawali, Nagrota Surian, Guler, Pong dam, Naduan, Pandoh and Sainj (Figure 5 and Figure 6). Three to four years of continuous data, freely available from the Bhakra Beas Management Board (BBMB) website was used. Sixteen interventions were implemented, taking location from WRIS. The characteristics of these interventions were extracted from India WRIS and National Register of Dams 2018. Out of 16 interventions present in the Pong Dam lake basin, characteristics of only six structures are available. Also, there is a link canal (Beas-Sutlej Link Canal) at Pandoh which transfers water from Pong Dam lake catchment to the neighbouring Sutlej catchment. Average annual releases and carrying capacity of the canal/tunnel are available in the literature, and the same has been used for simulation purpose. Timeseries data is available for shorter durations, but longer series availability will improve the outputs further. Elevation band to model the snow part has been implemented. Snowline is taken from the latest remote sensing images. Finally, the calibrated results are shown in Figure 7 to Figure 13.

There is scope for further refinement through long-term data from BBMB, but due to the pandemic situation, these data could not be obtained from BBMB.

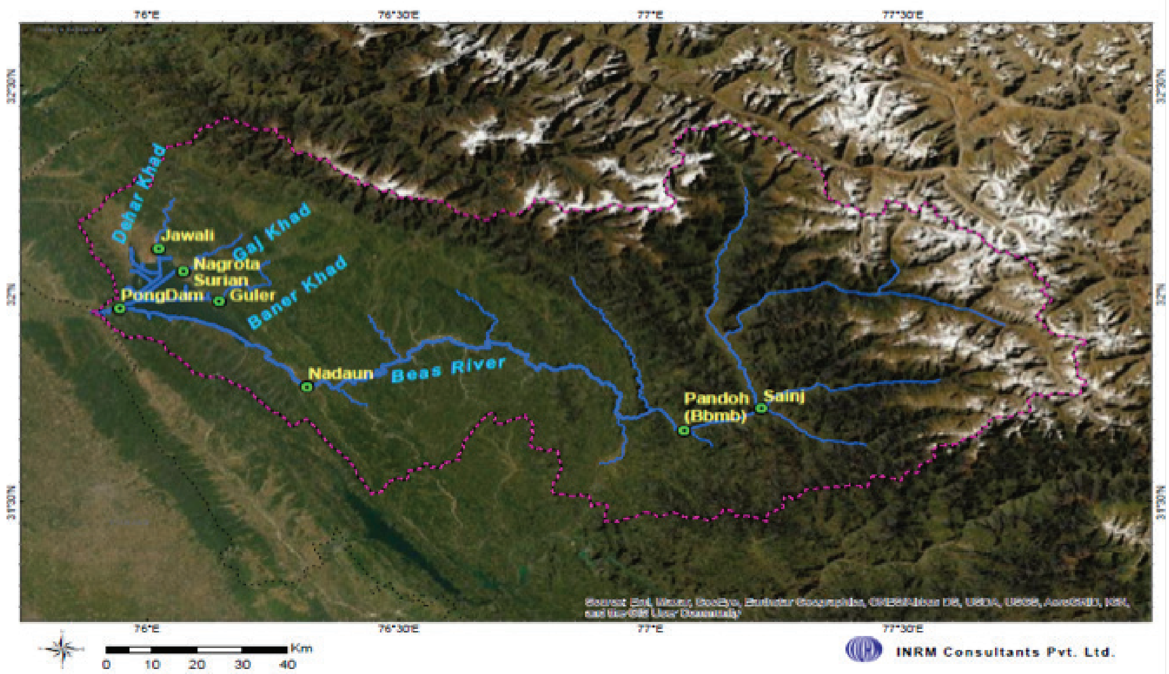


Figure 5 Gauge Locations in Pong Dam lake Catchment used for Calibration (Source: Model Output)

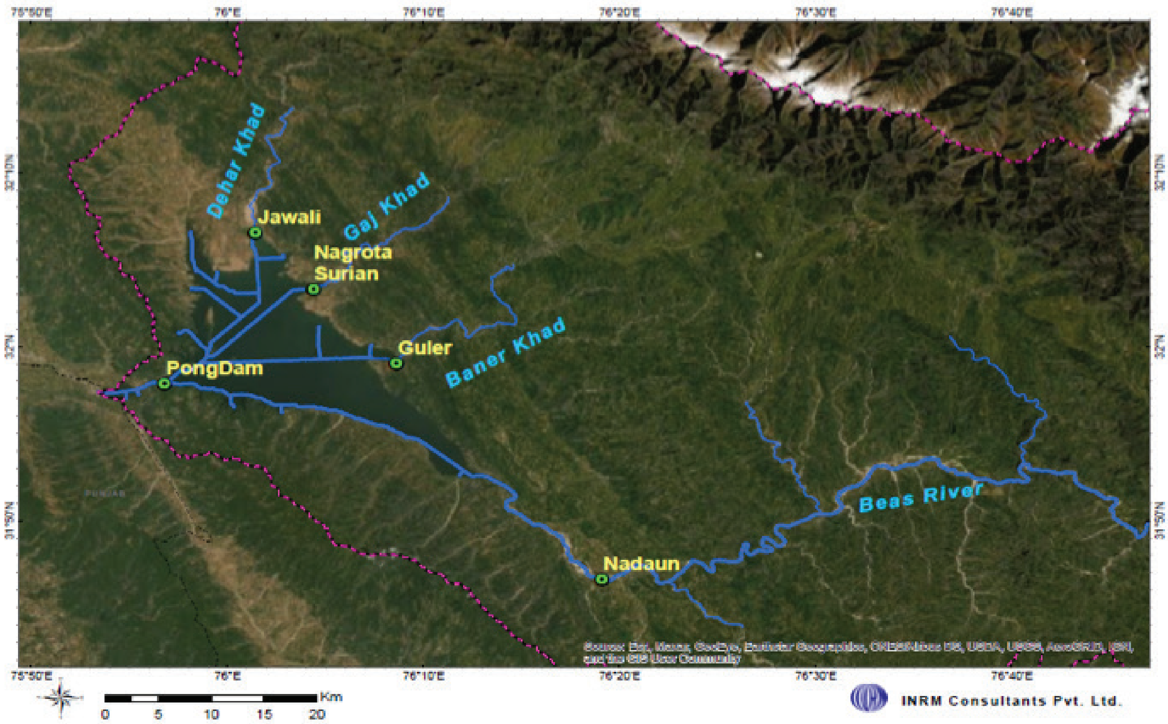


Figure 6 Gauge Locations near Pong Dam lake Wetland (Source: Model Output)

JAWALI

Jawali gauge is present upstream of the Pong Dam lake. It has one intervention (Sidhatha weir) upstream of the gauging station. Complete data of the upstream intervention is unavailable and could improve the calibration of the gauge location. It is evident from Jawali simulated results (Figure 7) that an intervention upstream of Jawali is not implemented and the storage in the structure is not taking place. This is an independent stream that joins Pong wetland and has a contributing area of 469 km^2.

The observed and simulated flow is plotted in Figure 7. The ranges of the model parameters are given in the table below. It is evident from the performance parameters that behaviour of the model is largely in the range of good to satisfactory, but it needs further fine-tuning and refinement of the data gaps.

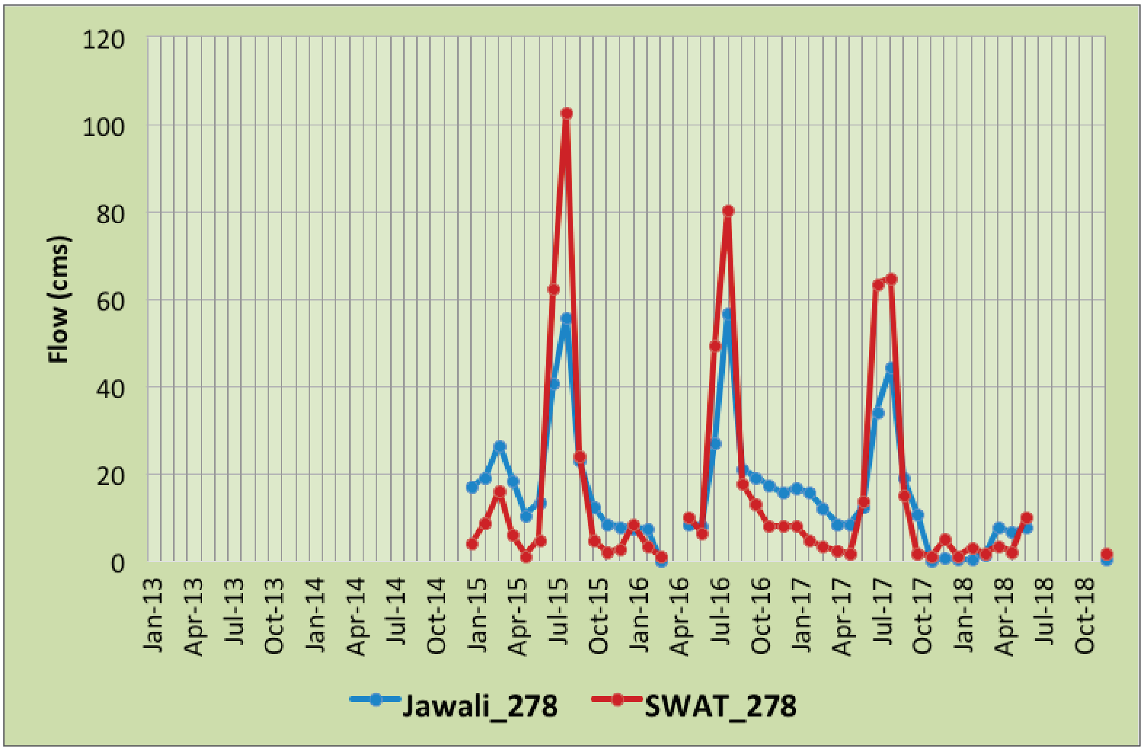


Figure 7 *Calibrated Results at Jawali*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Jawali	-0.8	0.92	0.56	0.67	15.4 (15.5)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

GULER

Guler is a gauge present upstream of Pong Dam lake reservoir with a contributing area of 723 km^2. It has one intervention upstream of the gauging station (Baner weir). Guler is an independent stream joining Pong Dam lake, and it is evident from Figure 8 that the data for the intervention and its diversion have to be provided properly. Nevertheless, the overall performance of the gauge falls in the range of good. The ranges of the model parameters are given in the table below. It is evident from the performance parameters that mostly behaviour of the model is in the range of good, but it can be further fine-tuned with availability of upstream data.

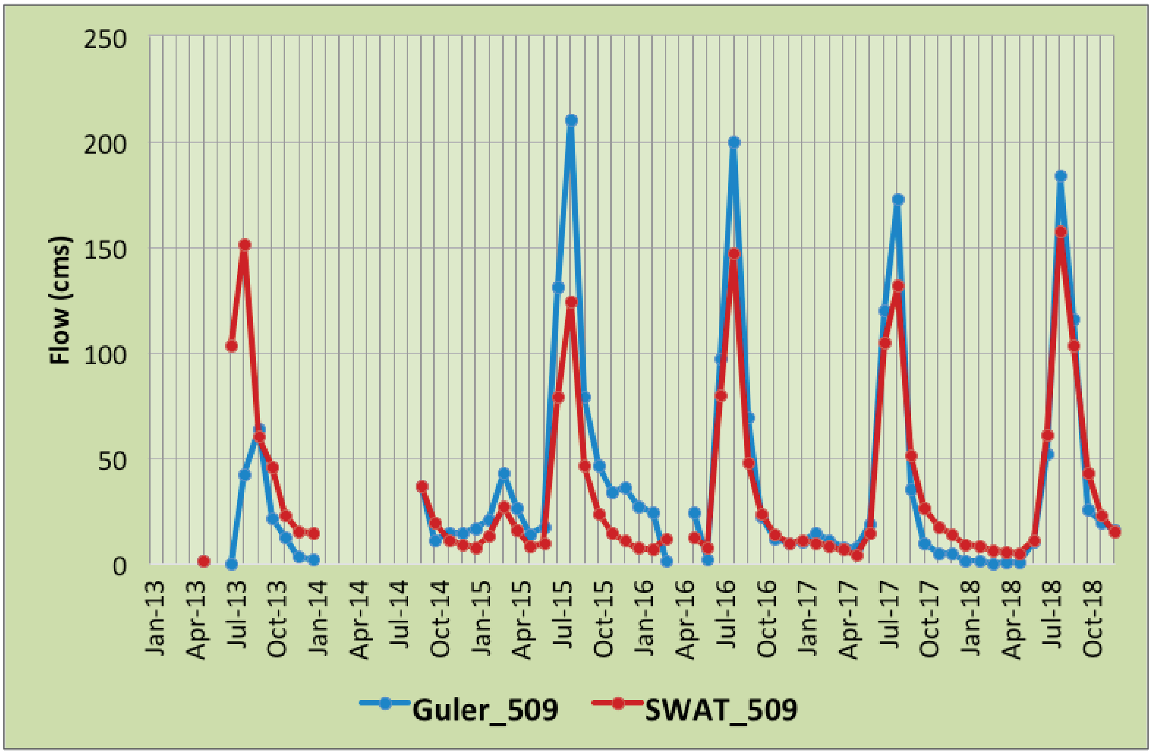


Figure 8 *Calibrated Results at Guler*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Guler	4.2	0.84	0.74	0.51	37.9 (36.3)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

PONG DAM LAKE

Pong Dam lake is the last gauge located at dam location. Data for this gauge location are available for model calibration. The observed and simulated flows are plotted in Figure 9 with ranges of the model parameters provided in the table below. It is evident from the performance parameters that behaviour of the model is largely in the range of very good, but it can be further fine-tuned with long-term data and upstream gauges.

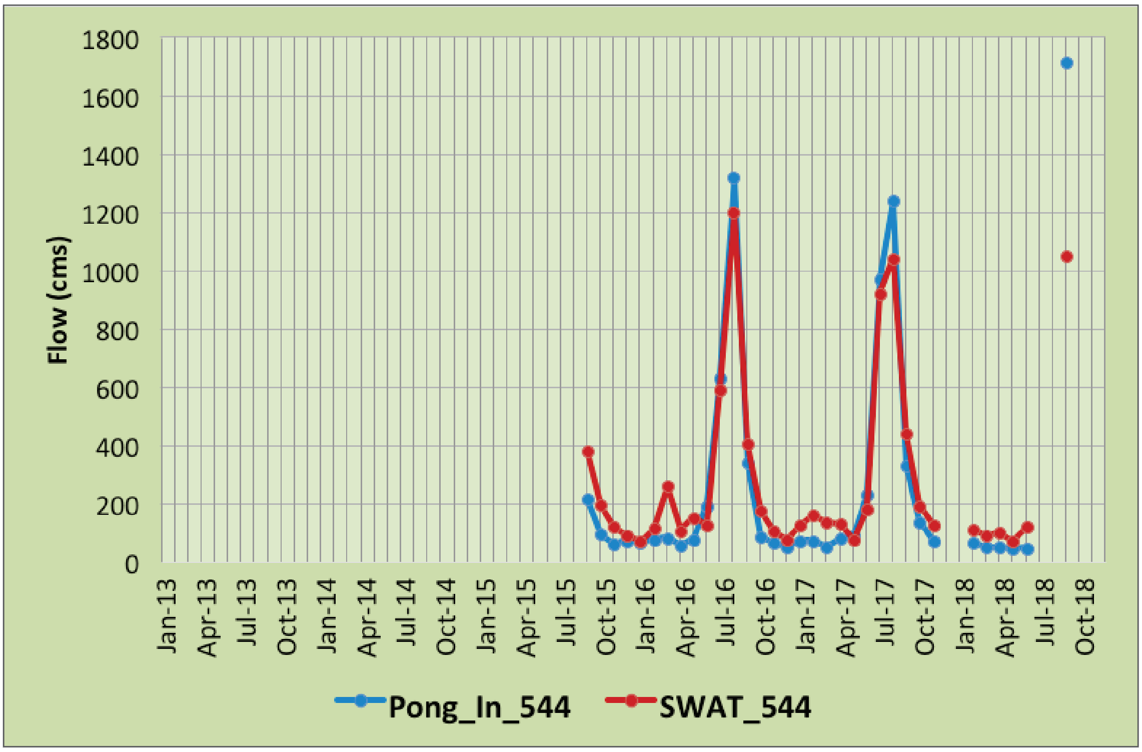


Figure 9 *Calibrated Results at Pong Dam Lake*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Pong Dam	-12.9	0.97	0.93	0.26	265.5 (299.8)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

NADUAN

Naduan is the gauge on the main Beas downstream of Pandoh Dam, between Pandoh Dam and Pong Dam lake. The observed and simulated flows are shown in Figure 10 with ranges of the model parameters given in the table below. It is evident from the performance parameters that the behaviour of the model is mostly very good, but it can be further fine-tuned with long-term continuous time series data of Beas-Sutlej Link Canal.

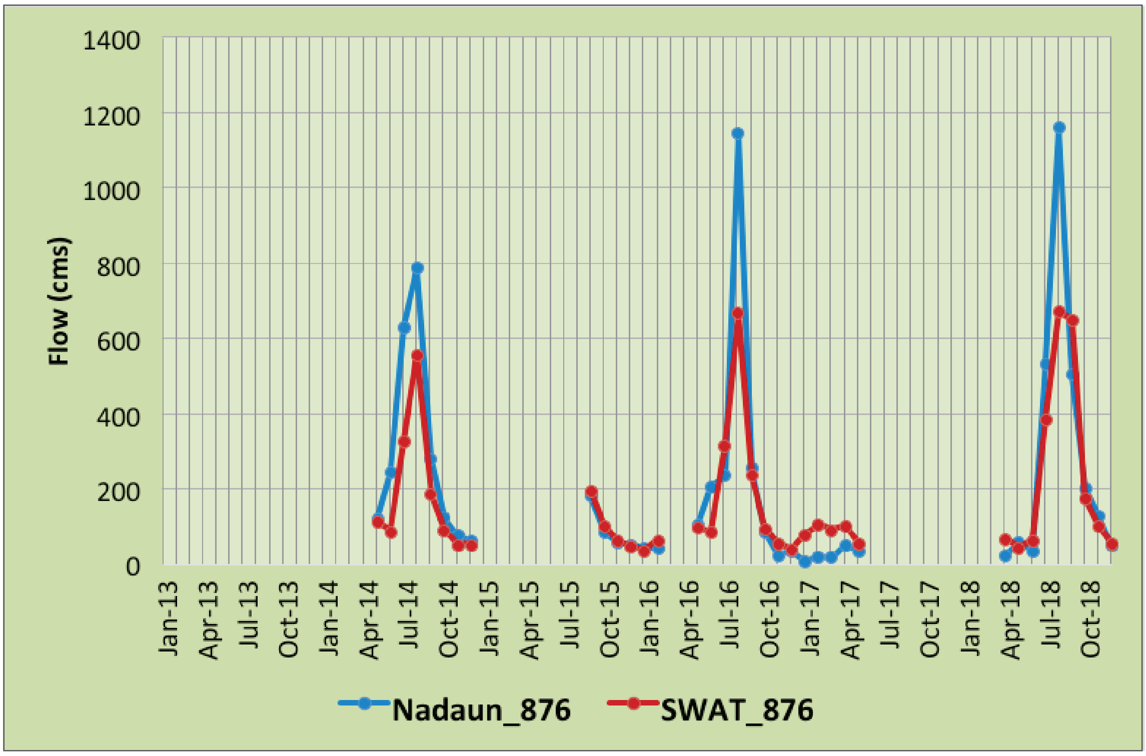


Figure 10 *Calibrated Results at Naduan*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Naduan	11.7	0.93	0.87	0.36	213.9 (188.9)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

NAGROTA SURIAN

Nagrota Surian is the gauge just upstream of Pong Dam lake with a contributing area of 411.3 km^2. Observed and simulated flows are plotted in Figure 11, and ranges of model parameters are given in the table below. It is evident from the performance parameters that behaviour of the model is in the range of good, but it can be further fine-tuned with time series data of upstream interventions and continuous time series data of the gauging station. It has one weir (Gaj weir) upstream of the gauge station, but data from this weir are unavailable. If data were to be available, the simulation can be improved further.

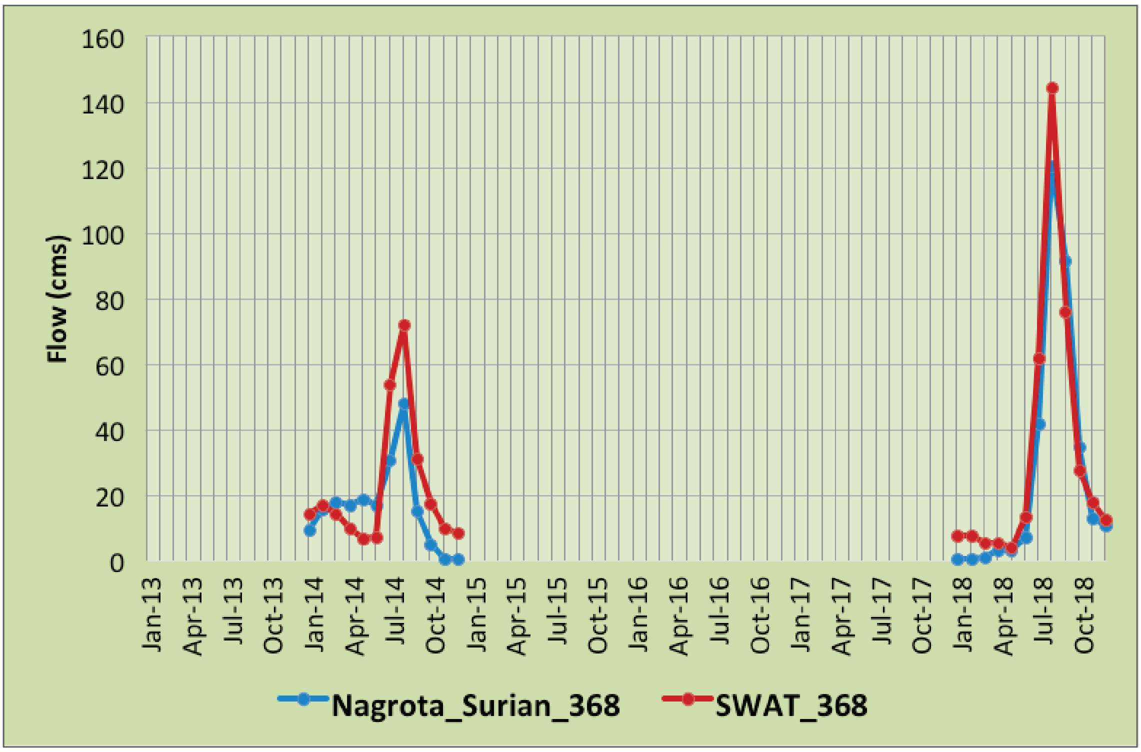


Figure 11 *Calibrated Results at Nagrota Surian*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Nagrota Surian	-20.6	0.94	0.93	0.26	21.7 (29.7)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

PANDOH

Pandoh is the gauge on the main Beas at the Pandoh Dam site. The observed and simulated flows are plotted in Figure 12, and ranges of the model parameters are given in the table below. It is evident from the performance parameters that the behaviour of the model is mostly satisfactory, but it can be further fine-tuned with long-term continuous time series data of the Beas-Sutlej Link Canal diversion. It is further evident from Figure 12 that diversion to the Beas-Sutlej Link Canal can change from year to year, and time series data will improve the calibration of the model.

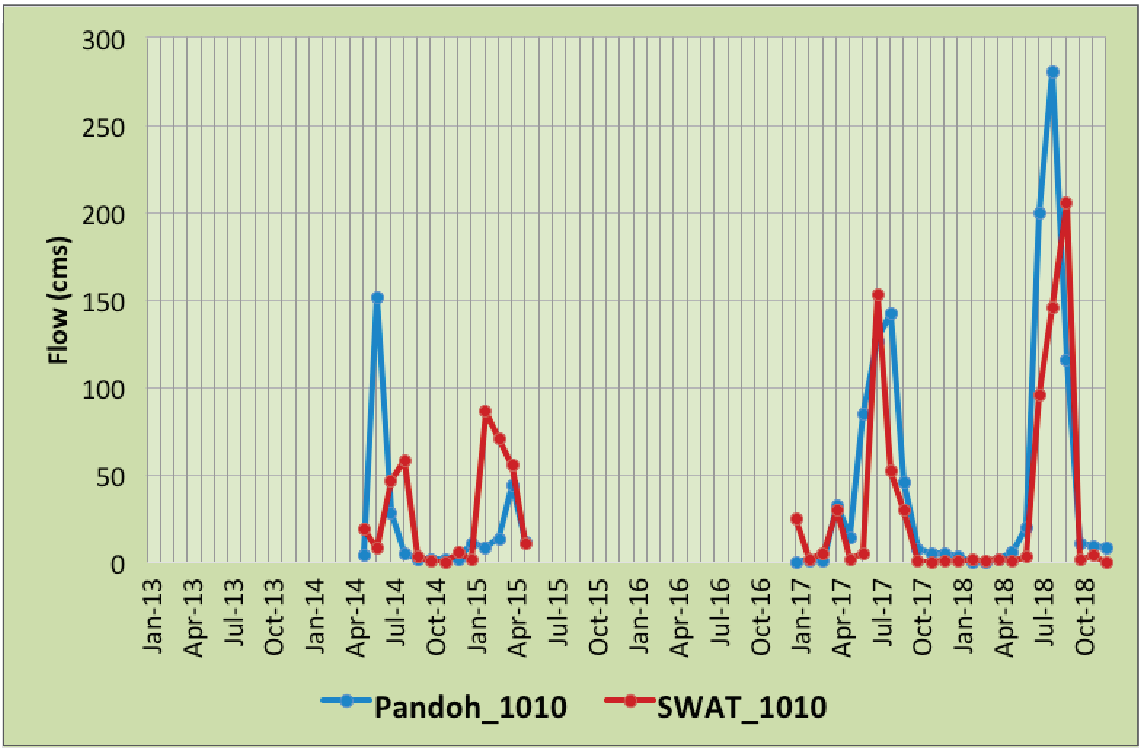


Figure 12 Calibrated Results at Pandoh
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Pandoh	8.9	0.68	0.57	0.66	37.9 (34.5)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

SAINJ

Sainj is the gauge on the main Beas upstream of Pandoh Dam. The observed and simulated flows are plotted in Figure 13, and ranges of model parameters are given in the table below. It is evident from the performance parameters that the behaviour of the model is mostly good to satisfactory, but it can be further fine-tuned with long-term time series data of upstream gauges.

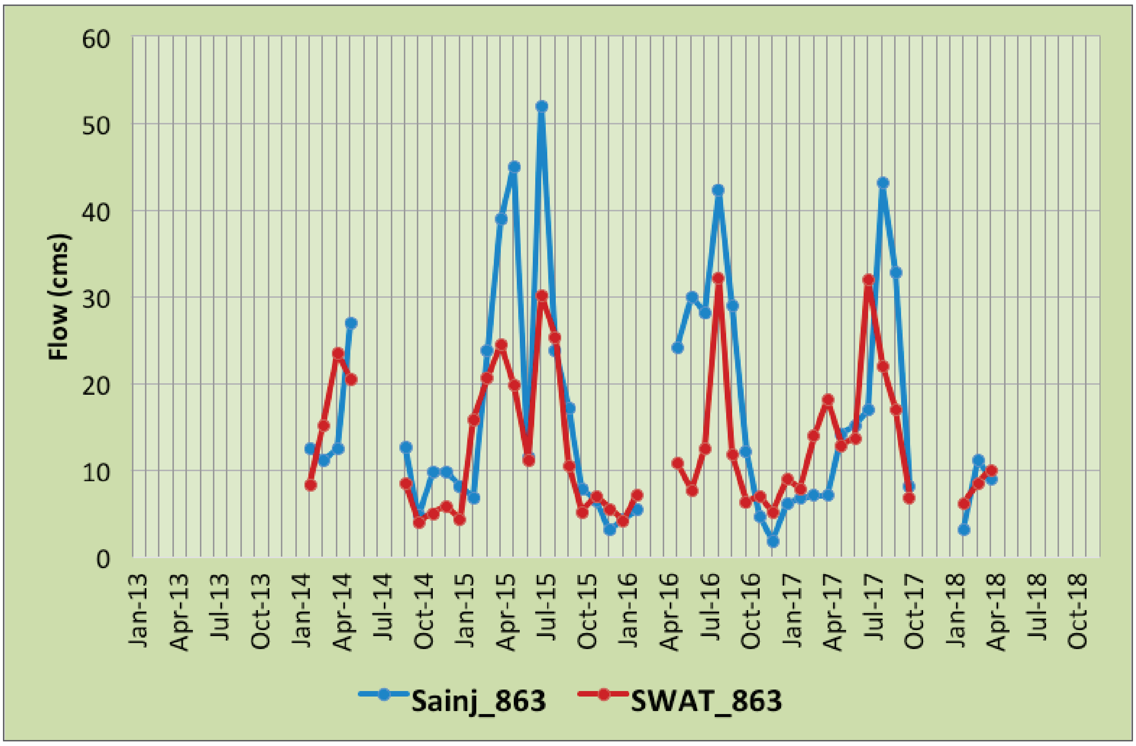


Figure 13 *Calibrated Results at Sainj*
(Source: Model Output)

Model performance parameters:

Site Name	PBIAS	Correlation Coefficient	COE/Nash	COE/Nash	Mean: Obs (SWAT)
Sainj	14	0.71	0.75	0.5	16.5 (14.2)

Range	NSE	RSR	PBIAS (%) + or -
V Good	0.75–1.0	0.0–0.5	<10
Good	0.65–0.75	0.5–0.6	10–15
Satisfactory	0.5–0.65	0.6–0.7	15–25
Unsatisfactory	<0.5	>0.7	>25

IMPACT OF LAND USE LAND COVER CHANGE

Land use land cover (LULC) have been continuously changing, through human activities, leading to variations in hydrological cycle. In this study, we applied the SWAT model to investigate potential impacts of LULC on the water budget of the Pong basin and wetland. It is observed that the LULC change had marginal effects on the hydrological processes in the basin but climate change was one of the main factors affecting run-off; and these land use changes had a significant impact on the water quality and sediment.

In the present study, the impact of land use land cover change on the health of the wetland has been analysed. Landsat-8 satellite images have been used for analysing the LULC of the years 2010 and 2020. The available images were selected based on the clarity of the image i.e. with minimum cloud cover. For the present study, supervised maximum likelihood classifier is used to classify the satellite images. LULC classes viz; built-up land, agricultural land, barren land, forest land, waterbodies, snow cover and river, were extracted from the satellite images, and supervised classification technique was used for the analysis. The satellite data were enhanced before classification using histogram equalization to improve the image quality and to achieve better classification accuracy. In supervised classification, spectral signatures are developed from specified locations in the image. Post classification, the maps were generated for the comparison and for statistical analysis of land use classes for both the periods. The decadal change in land use and landcover can be seen inFigure 14.

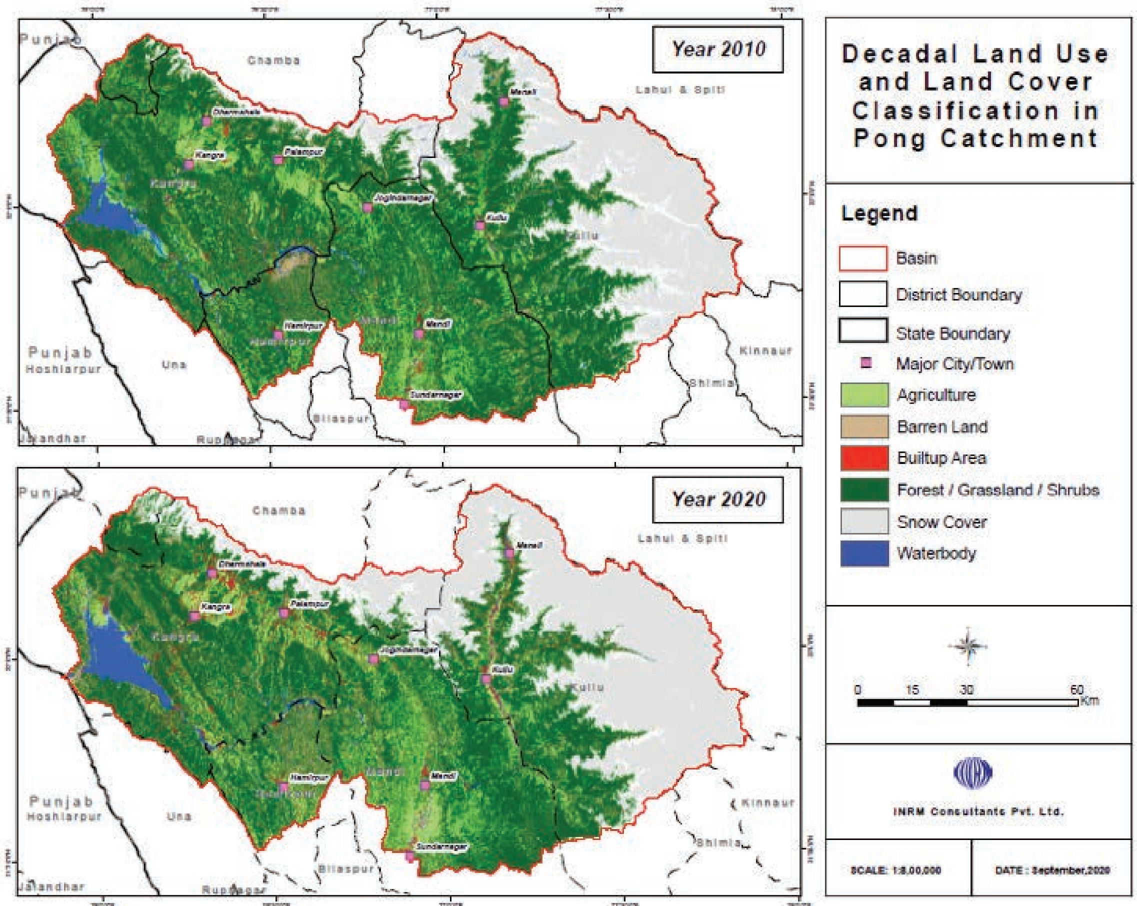


Figure 14 *Decadal Land Use and Land Cover Classification in Pong Dam lake Catchment (Source: Model Output)*

The agricultural area increased by 17%, and the built-up area has increased by 65% (see Table 1). In the Pong Dam lake catchment, forest land decreased by 8% and barren land decreased by 16% between 2010 and 2020. Table 1and Figure 14 indicate the conversion of forest land and barren land for agricultural purpose in the area. These conversions to agricultural land might increase the rate of sedimentation in the wetland, which in turn can affect hydropower production and reservoir storage capacity. Apart from the sedimentation issue, increase in agricultural land might affect the water quality of the wetland. This rate is likely to increase in the near future due to large-scale urbanization and development in the area, especially at major tourist places. Tourist places like Kullu, Manali, Dharmshala and Palampur are showing major changes in built-up area from year 2010 to year 2020.

Various sources in the literature also indicate that the land use land cover transformation at a few places/zones has been quite significant during the last decade in the Pong Dam lake area because of human and livestock activities in the surroundings (Malik et al., 2019). Major changes were observed in the agricultural land at the cost of other land use land cover, which might lead to increase in sedimentation in the wetland. These changes might affect the water quality of the wetland. With the help of remote sensing images, land use land cover change was analysed, but further refinement is needed with the help of ground truthing. In the present study, ground truthing could not be undertaken because of travel restrictions imposed due to the ongoing pandemic. The percentage change in land use land cover in the decade from 2010 to 2020 is shown in Table 1.

Table 1 *Percentage Change in Land Use/Land Cover in the Decade from 2010 to 2020*

Land Use Classes	Area 2010 (%)	Area 2020 (%)	Percentage Change (2010 to 2020)
Agriculture	11.56	13.49	16.7
Barren Land	6.39	5.34	-16.43
Built-up Area	1.8	2.98	65.56
Forest	53.04	48.65	-8.28
Snow	24.64	25.95	5.32
River Channel	1.85	2	8.11
Water Body	0.83	1.69	103.61

Actual National Remote Sensing Centre (NRSC) land use data of 2007–2008 were used for model simulation. On the calibrated model, 2019-2020 Landsat-8/Sentinel images were used to simulate the impact of land use land cover on the hydrology of the basin. To analyse the impact of land use change on the flow regime, a comparison of land use change between Pandoh and Pong was done, which is shown in Figure 15 and Figure 16. It is evident from the graphs at Pandoh and Pong that land use change is not impacting the flow regime of the basin drastically. Water quality comparison could not be done for this scenario in the absence of data for calibrating the model.

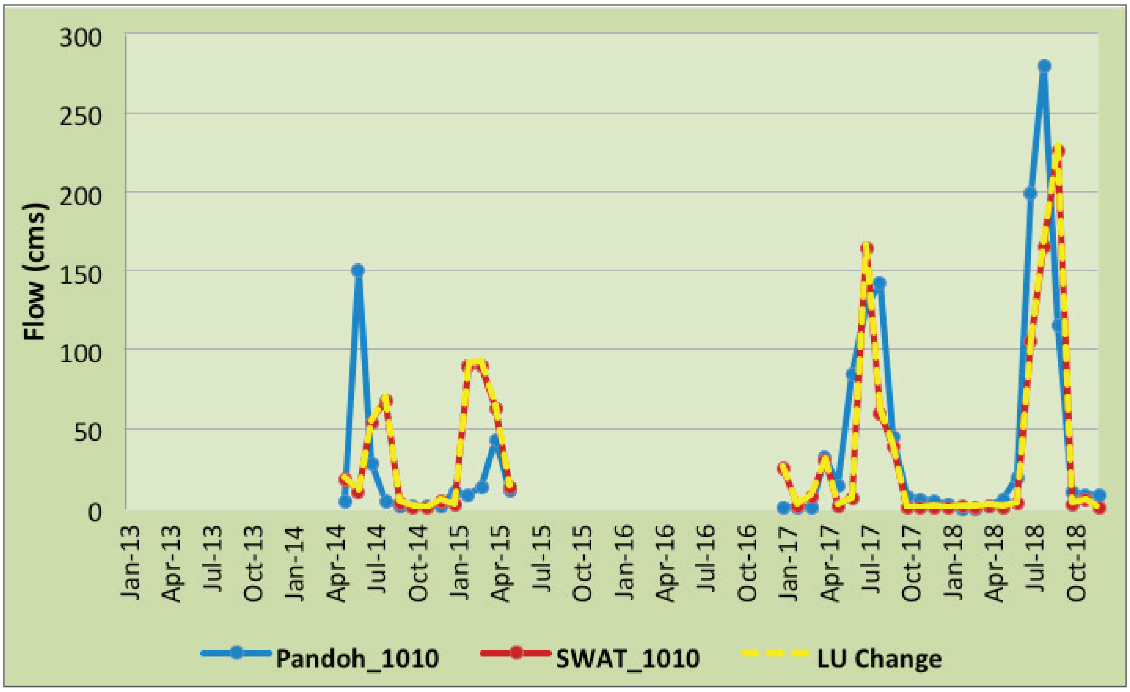


Figure 15 *Flow Comparison at Pandoh with Land Use Change*
(Source: Model Output)

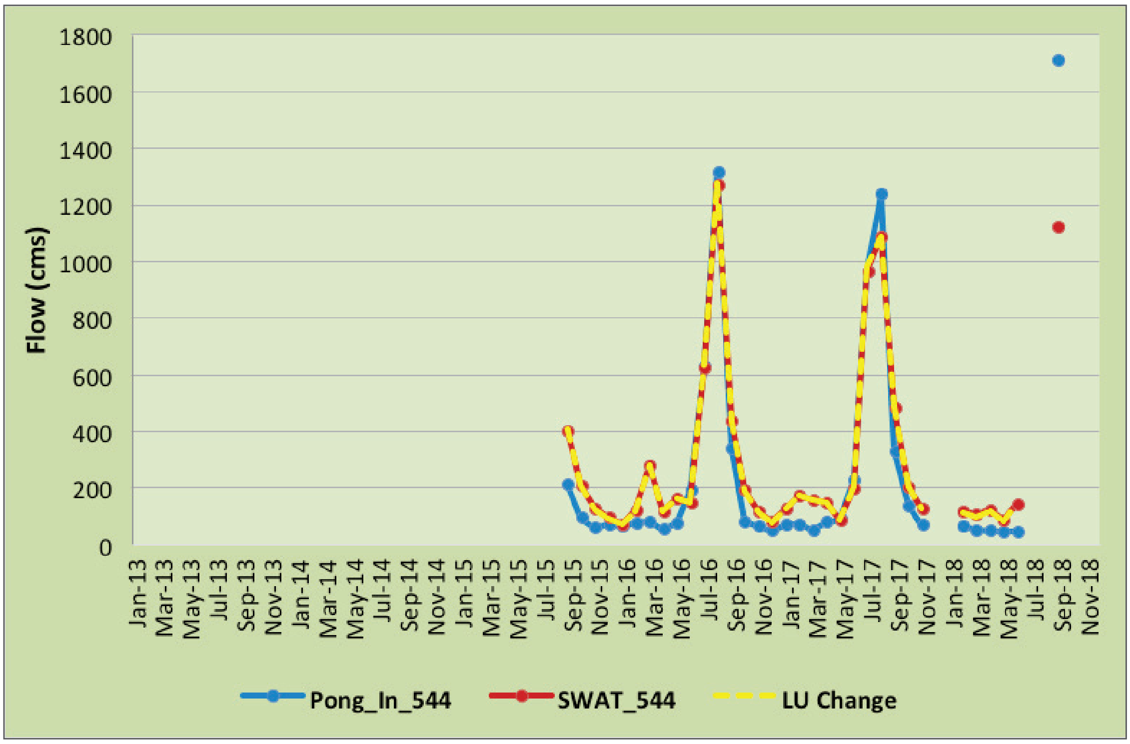


Figure 16 *Flow comparison at Pong Dam lake with Land Use Change*
(Source: Model Output)

CLIMATE CHANGE

Himachal Pradesh is not only an important water source for its own habitats, but it is also a source of water to other states for the purpose of drinking water supply, irrigation and power generation. Rainfall and stream flows are highly variable. Climate change presents significant additional challenges for the managers of water resources in Himachal Pradesh. Improved knowledge is needed to assist water managers to understand the wide range of impact that climate change will have on surface and groundwater resources, and on the demand for water. For analysing water resource availability, the SWAT model has been simulated with the climate change data.

The CORDEX South Asia-modelled climate data on precipitation, maximum temperature, minimum temperature and climate extreme indices have been analysed for Pong Dam lake basin and districts falling within Pong catchment, for baseline (BL, 1981–2010), mid-century (MC, 2021–2050) and end-century (EC, 2071–2100). Projected change in climate for precipitation, maximum temperature and minimum temperature has been assessed for the study area. Resolution of the projected climate data is at a grid-spacing of 0.5°×0.5° for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) scenarios, namely, RCP 8.5 (a scenario of comparatively high greenhouse gas emissions which does not include climate policy interventions) and RCP 4.5 (a moderate emission scenario which assumes climate policy intervention to transform associated reference scenarios). Ensemble mean of three regional climate models (RCMs), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO) has been used for the analysis. Ensemble mean is chosen to reduce model-related uncertainties, and ensemble mean climate is closer to the observed climate than any individual model.

The CORDEX South Asia simulations with the models indicate an all-round warming over the Pong basin. Projected temperature increase towards EC is higher than that of MC. For IPCC AR5 RCP 4.5 and RCP 8.5 scenarios, the minimum temperature shows higher projected increase than the maximum temperature towards MC and EC for Pong basin. However, the IPCC AR5 RCP8.5 shows higher increase than the IPCC AR5 RCP4.5.

TEMPERATURE PROJECTIONS FOR PONG DAM LAKE BASIN

ANALYSIS OF PROJECTED MAXIMUM TEMPERATURE

Ensemble means of the CORDEX South Asia climate data for IPCC AR5 RCP4.5 and RCP8.5 scenarios for Pong Dam lake basin and districts falling within it have been analysed for the annual and seasonal maximum temperature. The projected annual and seasonal maximum temperature changes towards mid century and end century with respect to BL for Pong Dam lake basin and districts falling in it for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios are given in Appendix I (Table 7 and Table 8 respectively). Figure 17 and Figure 18 show projected changes in annual and seasonal maximum temperature towards MC and EC with respect to BL for Pong basin and districts falling in it for IPCC AR5 RCP4.5 and RCP8.5. The same has also been depicted as a line graph (Figure 17 and Figure 18) for Pong basin and as a bar graph for the districts. The seasonal changes for the basin towards MC and EC with respect to BL are also shown for both IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The spatial representation of projected changes in annual and seasonal mean maximum temperature for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios is shown in Figure 19 and Figure 20, respectively.

Summary of the projected change in maximum temperature for IPCC AR5 RCP4.5 and RCP8.5 scenarios is as follows:

- The average annual maximum temperature for the IPCC AR5 RCP4.5 scenario is projected to increase by about 1.5°C towards MC and by 2.8°C towards EC, while for the IPCC AR5 RCP 8.5 scenario, it is projected to increase by about 1.8°C towards MC and 5.3°C towards EC for Pong basin. Thus, projected temperature increase in EC is higher than that of MC.

- The projected increase in maximum temperature towards MC varies from 1.3°C in Hamirpur lying in the southern region to 1.6°C in Chamba district for the IPCC AR5 RCP 4.5 scenario, and 1.5°C in Hamirpur to 1.9°C in Kullu district of Pong Dam lake basin for the IPCC AR5 RCP 8.5 scenario as shown in Figure 17 to Figure 20.
- The projected increase in maximum temperature towards EC varies from 2.2°C in Hamirpur to 3.0°C in Chamba district for the IPCC AR5 RCP 4.5 scenario and 4.6°C in Hamirpur to 5.7°C in Chamba district of Pong Dam lake basin for the IPCC AR5 RCP 8.5 scenario as shown in Figure 17 and Figure 20.
- The highest maximum temperature increase is projected in winter season (January, February (JF)) for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios towards MC and EC for Pong Dam lake basin as compared to the other seasons -(Figure and Figure 20).

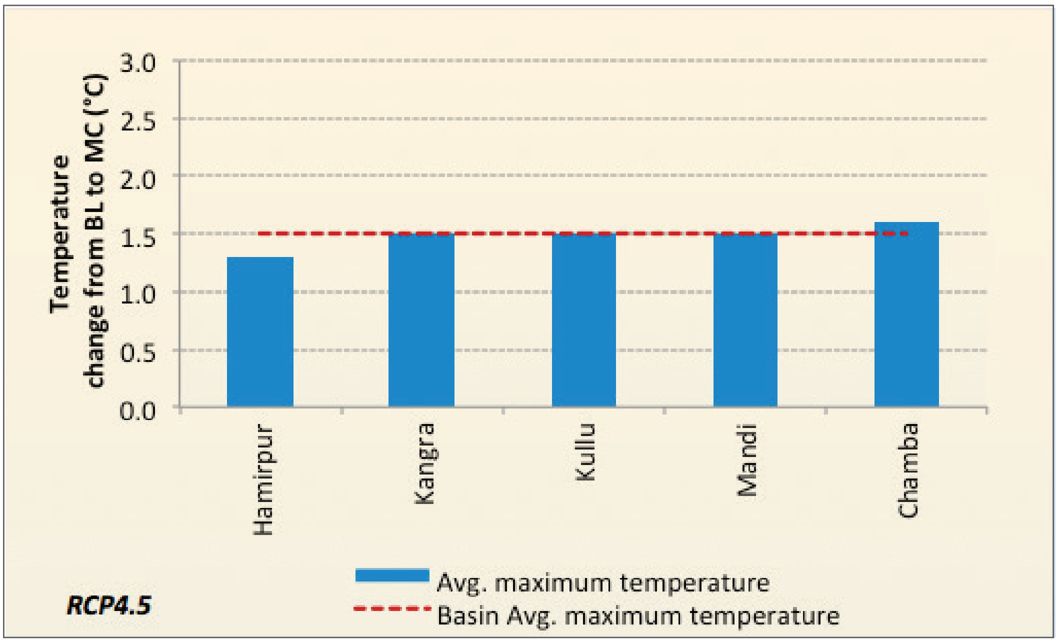


Figure 17 (a) *Characteristics of projected annual and seasonal maximum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

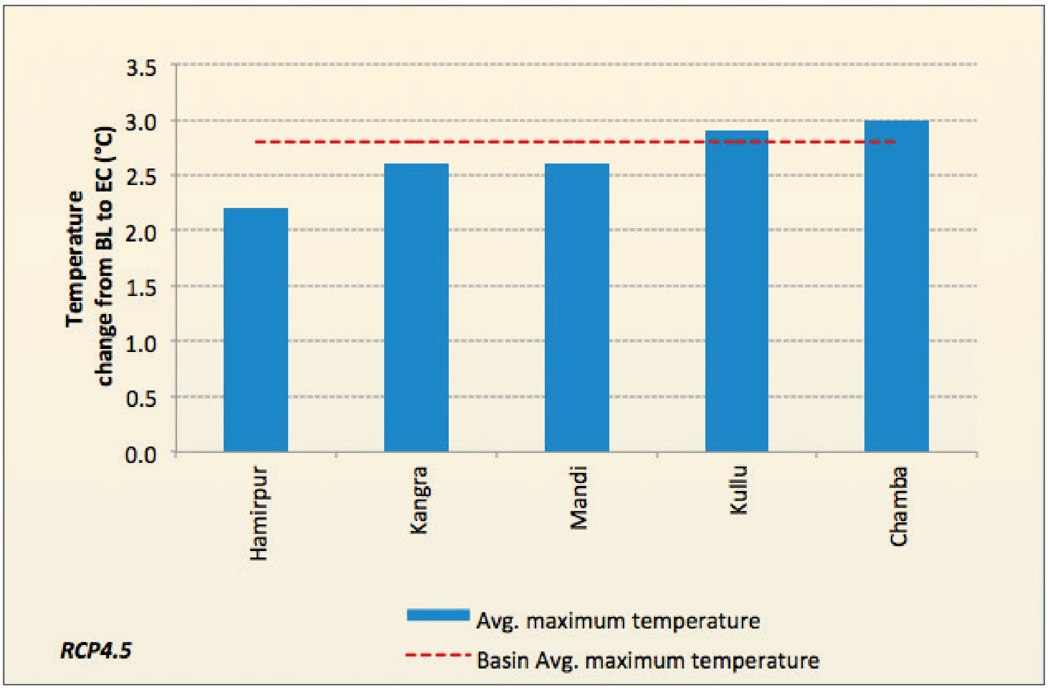


Figure 17 (b) *Characteristics of projected annual and seasonal maximum temperature (BL to MC) for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

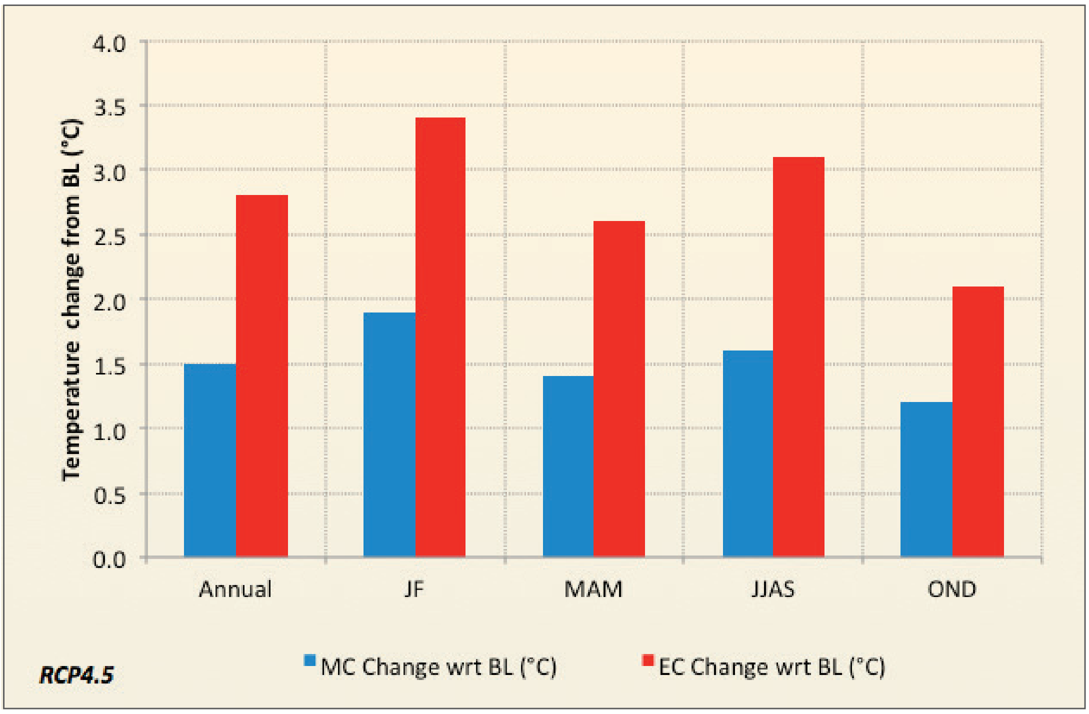


Figure 17 (c) *Characteristics of projected annual and seasonal maximum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

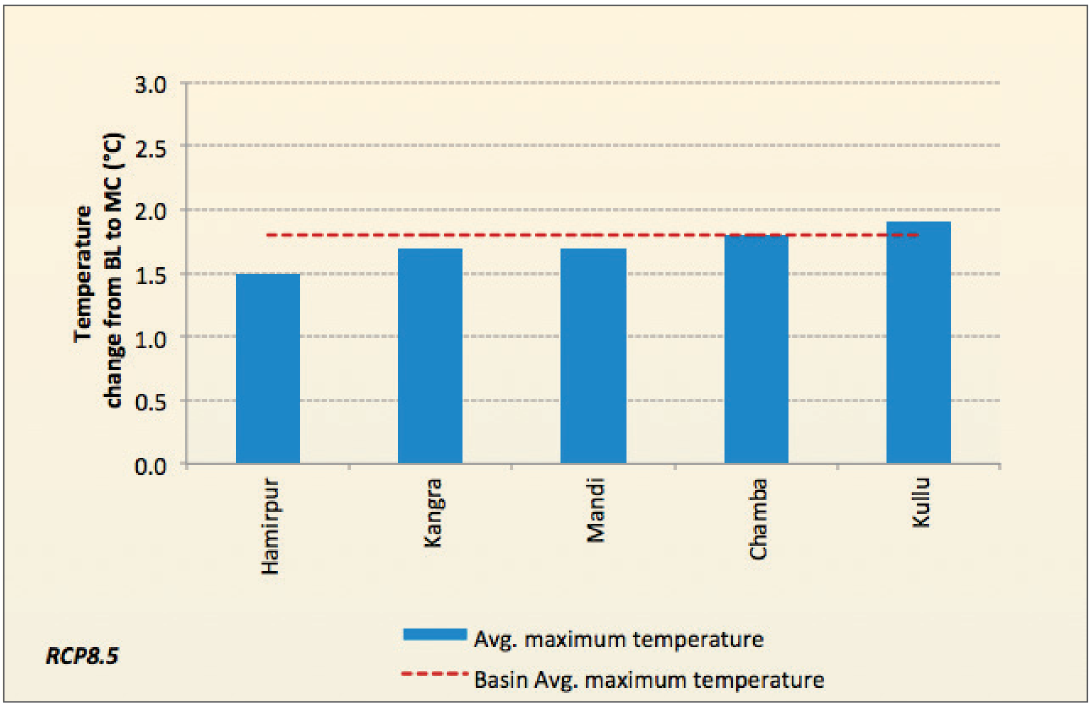


Figure 18 (a) *Characteristics of projected change (BL to MC) in annual maximum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

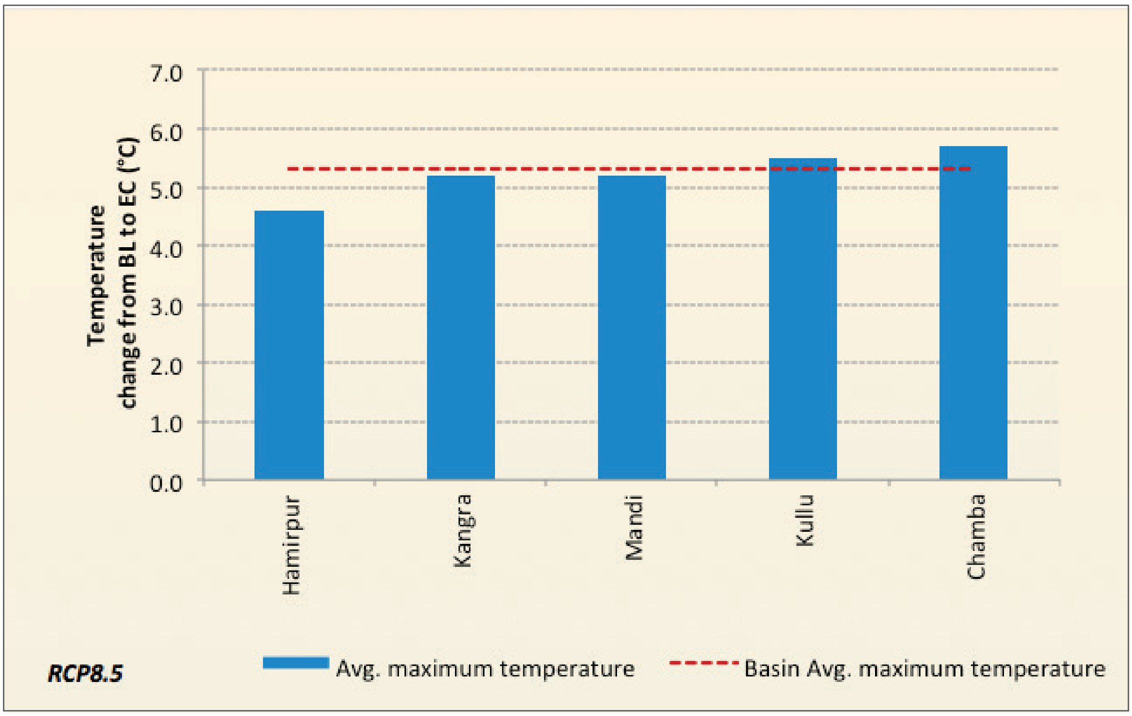


Figure 18 (b) *Characteristics of projected change (BL to MC) in annual maximum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

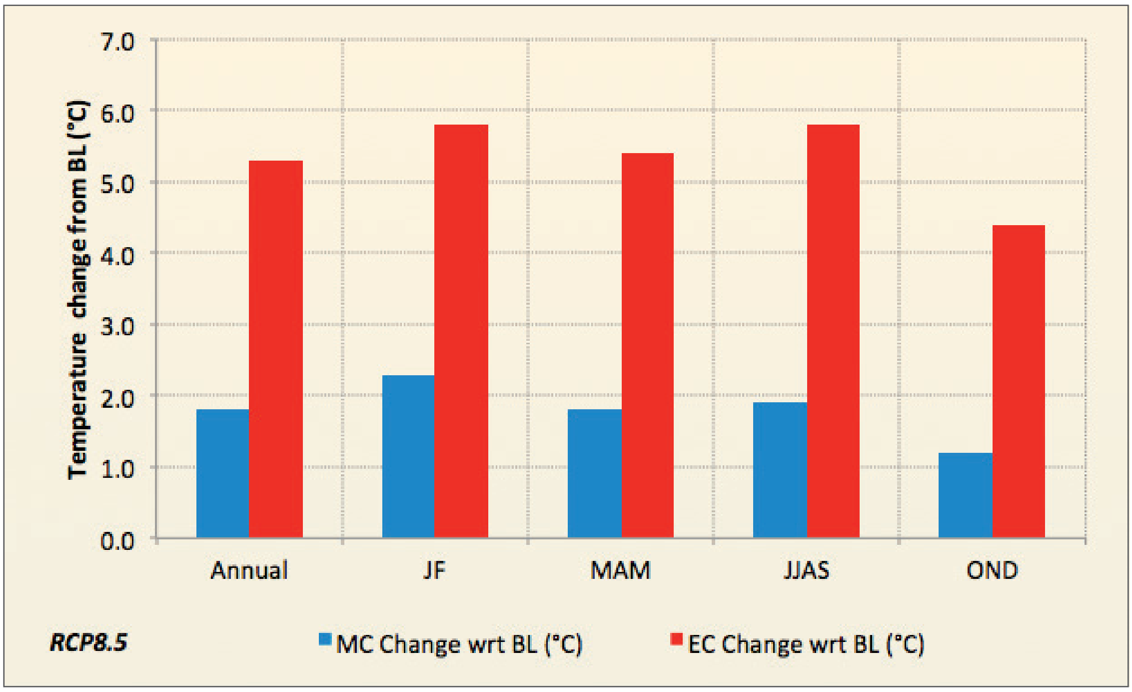


Figure 18 (c) *Characteristics of projected annual and seasonal maximum temperature change for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

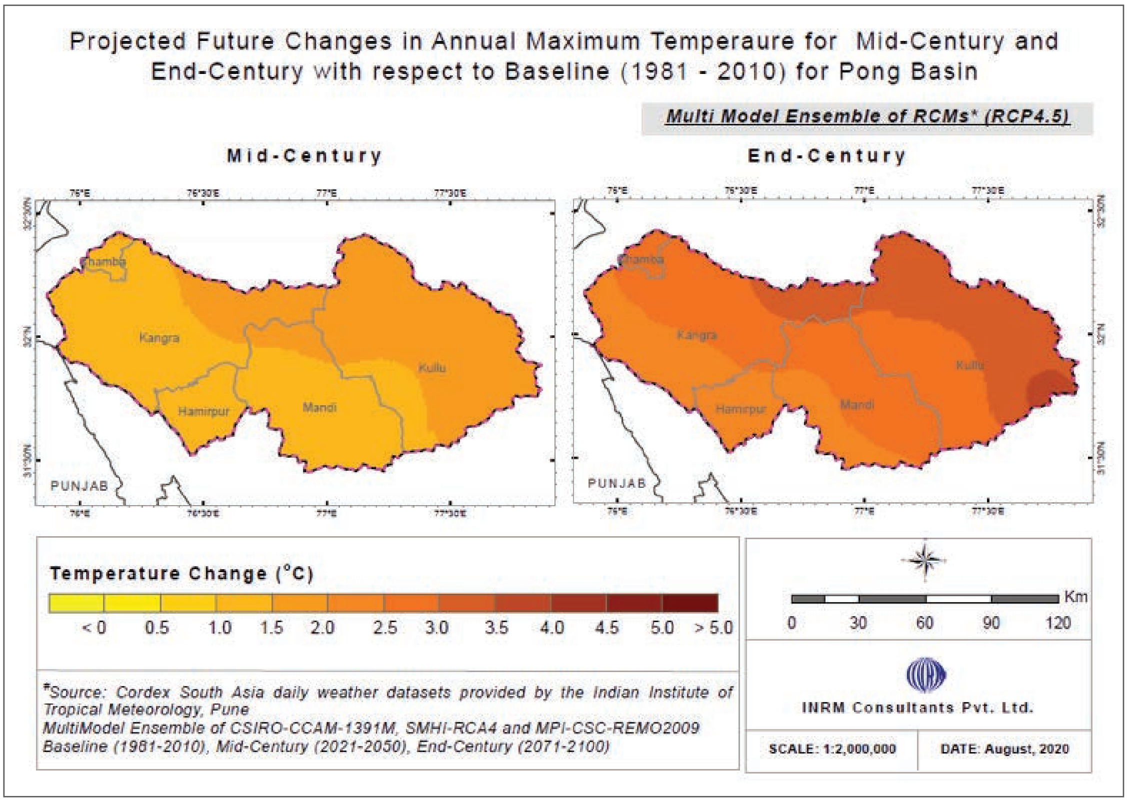


__Figure 19 (a)__ Spatial representation of projected changes in annual and seasonal maximum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin

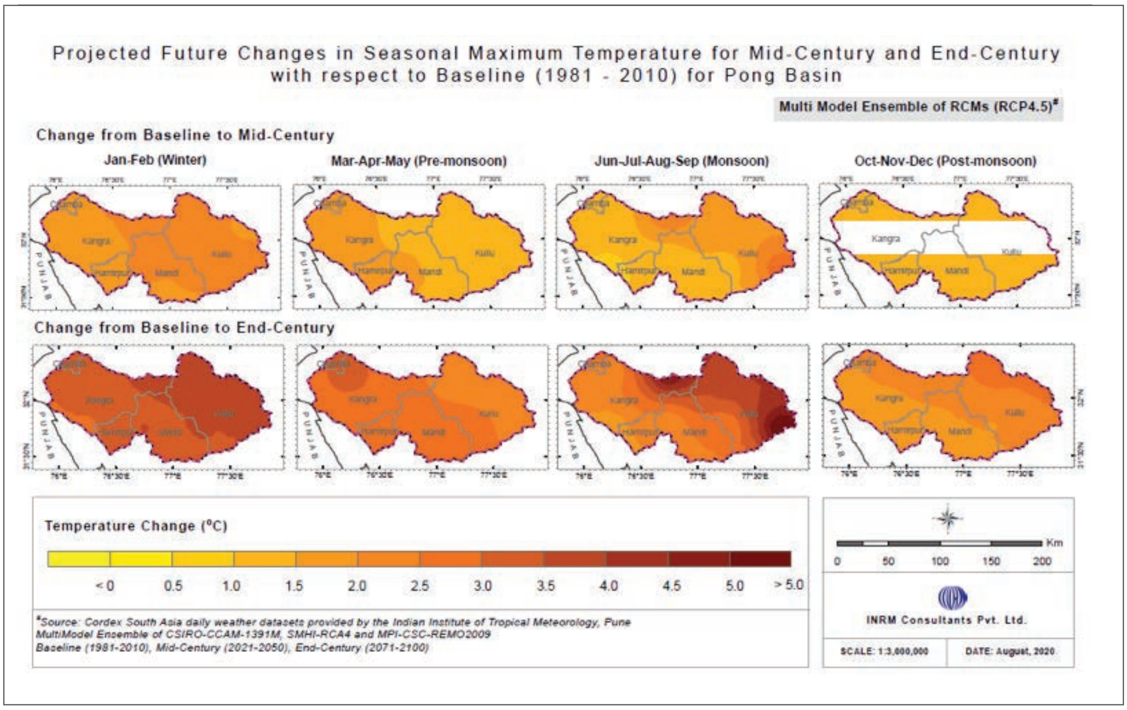


__Figure 19 (b)__ Spatial representation of projected changes in seasonal maximum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin

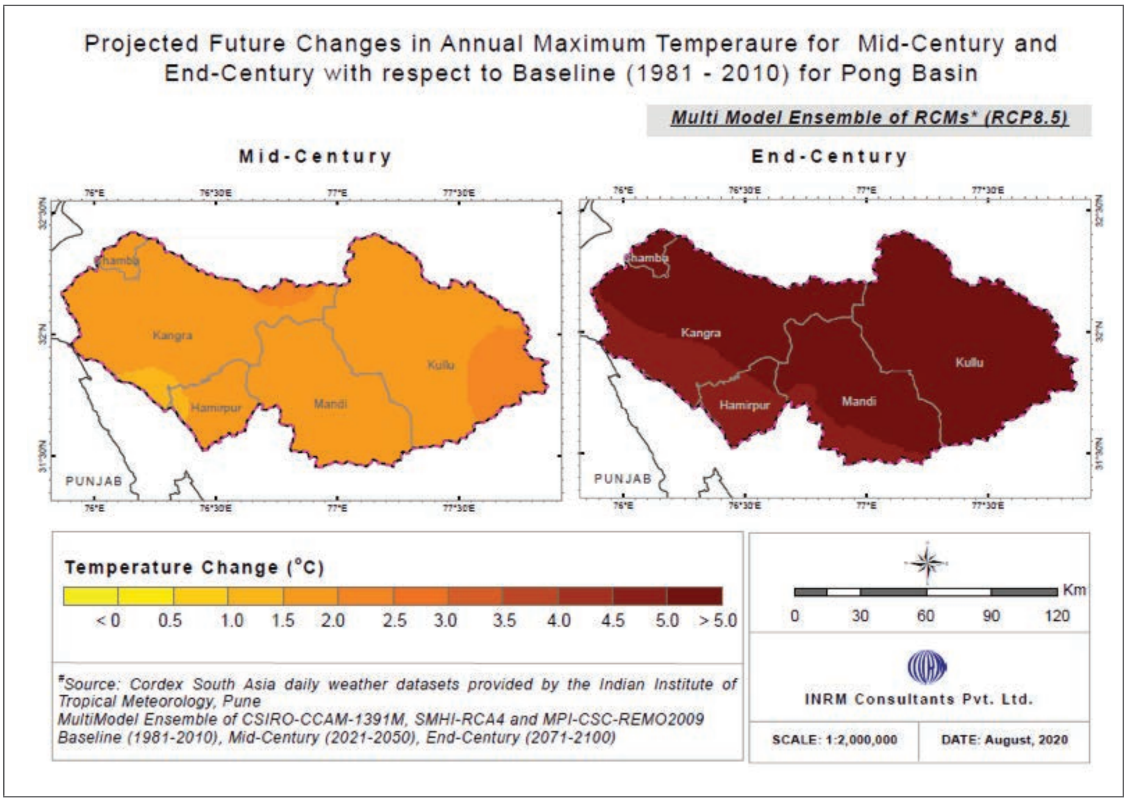


Figure 20 (a) *Spatial representation of projected changes in annual maximum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

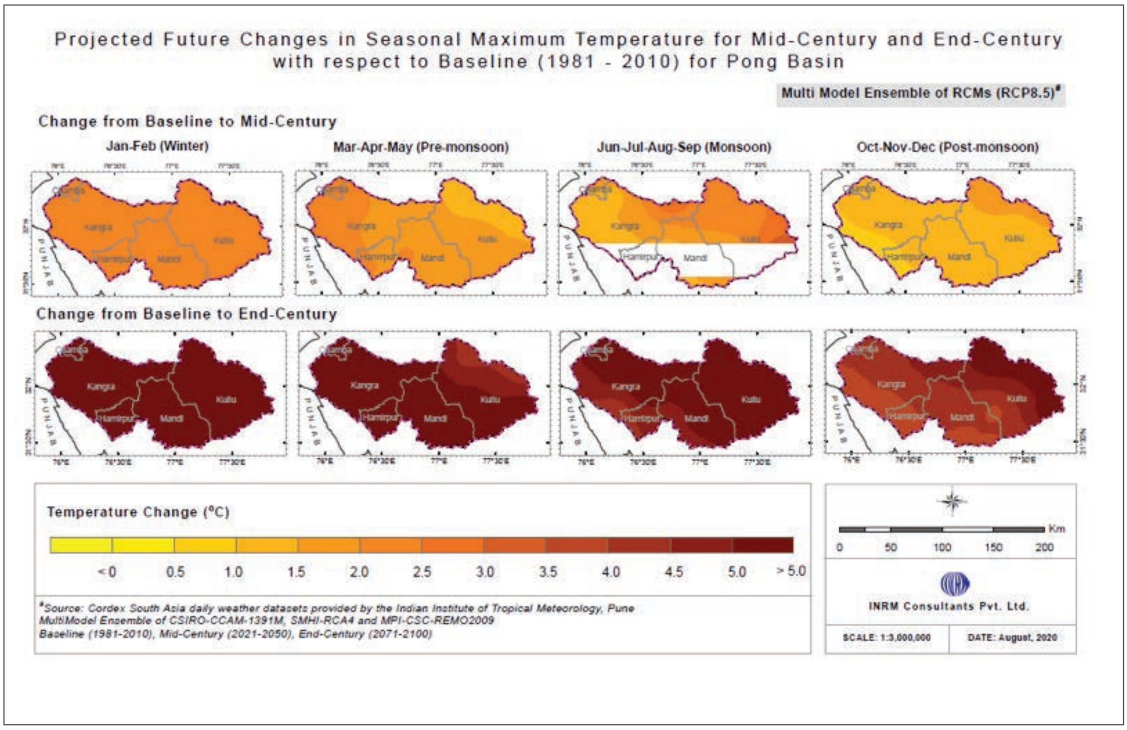


Figure 20 (b) *Spatial representation of projected changes in seasonal maximum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

ANALYSIS OF PROJECTED MINIMUM TEMPERATURE

Ensemble means of the CORDEX South Asia climate data for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios for Pong Dam lake basin and districts falling in it for the annual and seasonal minimum temperature have been analysed. The projected annual and seasonal minimum temperature changes towards MC and EC with respect to BL for Pong basin and districts falling in it for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios are given in Appendix I (Table 9 and Table 10 respectively).

Figure 21 and Figure 22 show projected change in annual and seasonal minimum temperature towards MC and EC with respect to BL for Pong basin and districts falling in it for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The same has also been depicted as a line graph for Pong basin and as a bar graph for the districts. The seasonal changes for the Pong basin towards MC and EC with respect to BL are also shown for both IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The spatial representation of projected changes in annual and seasonal mean minimum temperature for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios is shown in Figure 23 and Figure 24 respectively.
Summary of the projected change in minimum temperature for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios is as follows:

- The average annual minimum temperature for the IPCC AR5 RCP 4.5 scenario is projected to increase by about 1.4°C towards mid-century (MC) and by 2.7°C towards end-century (EC), while for the IPCC AR5 RCP 8.5 scenario it is projected to increase by about 1.8°C towards MC and 5.0°C towards EC for Pong basin. Thus, projected temperature increase towards EC is higher than that of MC.
- The projected increase in minimum temperature towards MC does not show much variability across the basin for the IPCC AR5 RCP 4.5 scenario, while it varies from 1.7°C in Hamirpur and Mandi to 1.9°C in Chamba of Pong basin for the IPCC AR5 RCP 8.5 scenario as shown in Figure 21 to Figure 24.
- The projected increase in minimum temperature towards EC varies from 2.6°C to 2.9°C in Chamba district for the IPCC AR5 RCP 4.5 scenario and 4.8°C in Kullu to 5.4°C in Chamba district of Pong basin for the IPCC AR5 RCP 8.5 scenario as shown in Figure 21 and Figure 24.
- The highest minimum temperature increase is projected in monsoon season (June, July, August, September (JJAS)) for IPCC AR5 RCP 4.5 and RCP 8.5, for both MC and EC for Pong basin as compared to the other seasons (Figure 21 and Figure 24).

For both IPCC AR5 RCP 4.5 and RCP 8.5 scenarios, increase in annual and seasonal minimum temperature is projected for Pong basin and districts falling in it towards MC and EC. However, the IPCC AR5 RCP 8.5 scenario shows a higher increase than the IPCC AR5 RCP 4.5 scenario.

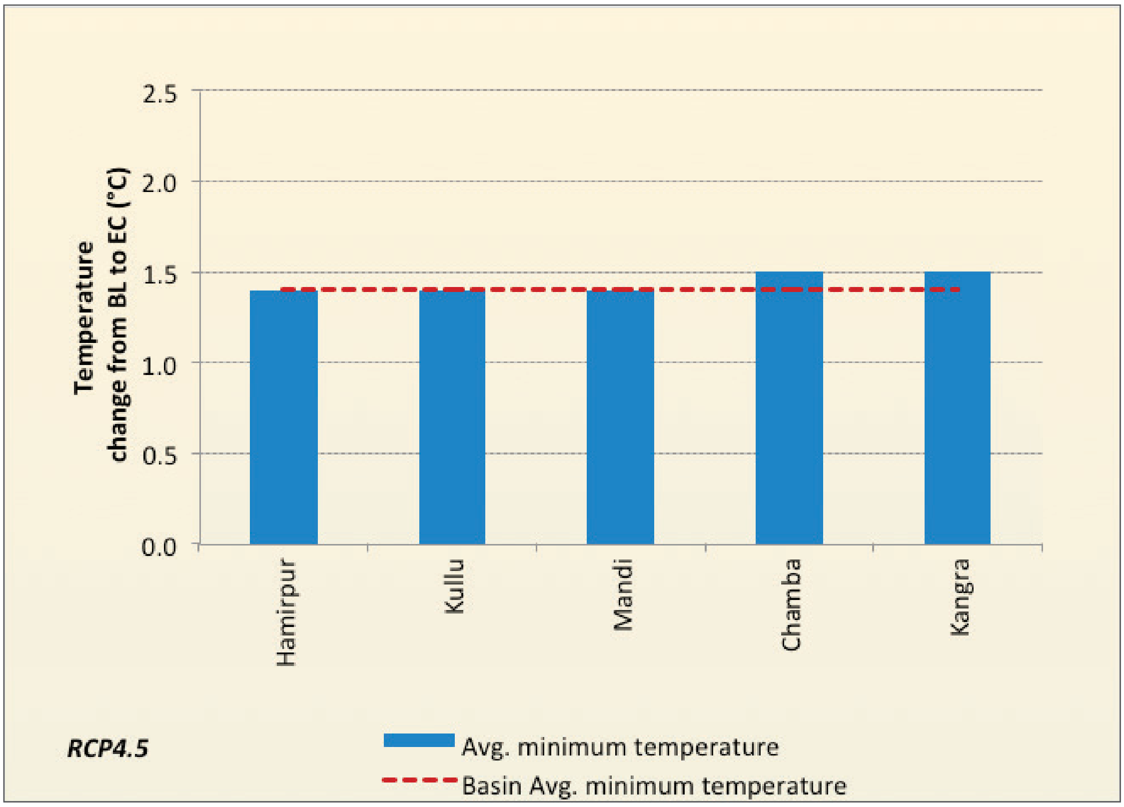


Figure 21 (a) *Characteristics of projected changes (BL to MC) in annual minimum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

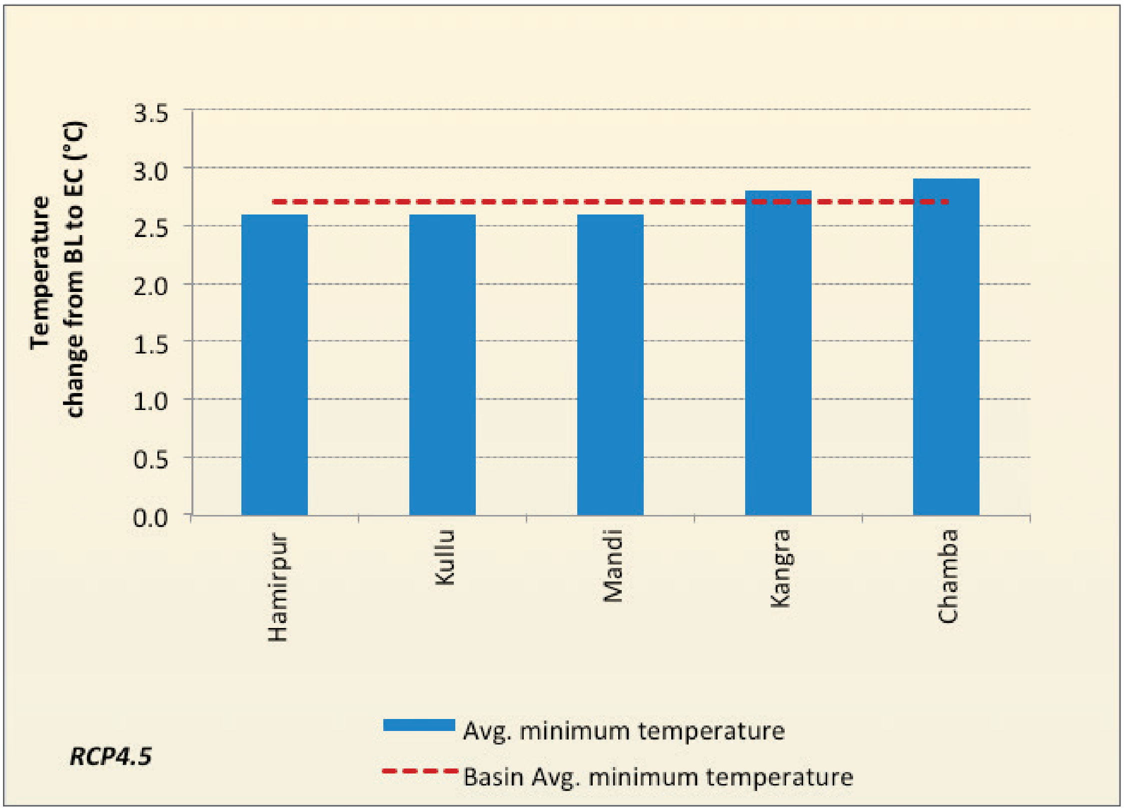


Figure 21 (b) *Characteristics of projected changes (BL to EC) in annual minimum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

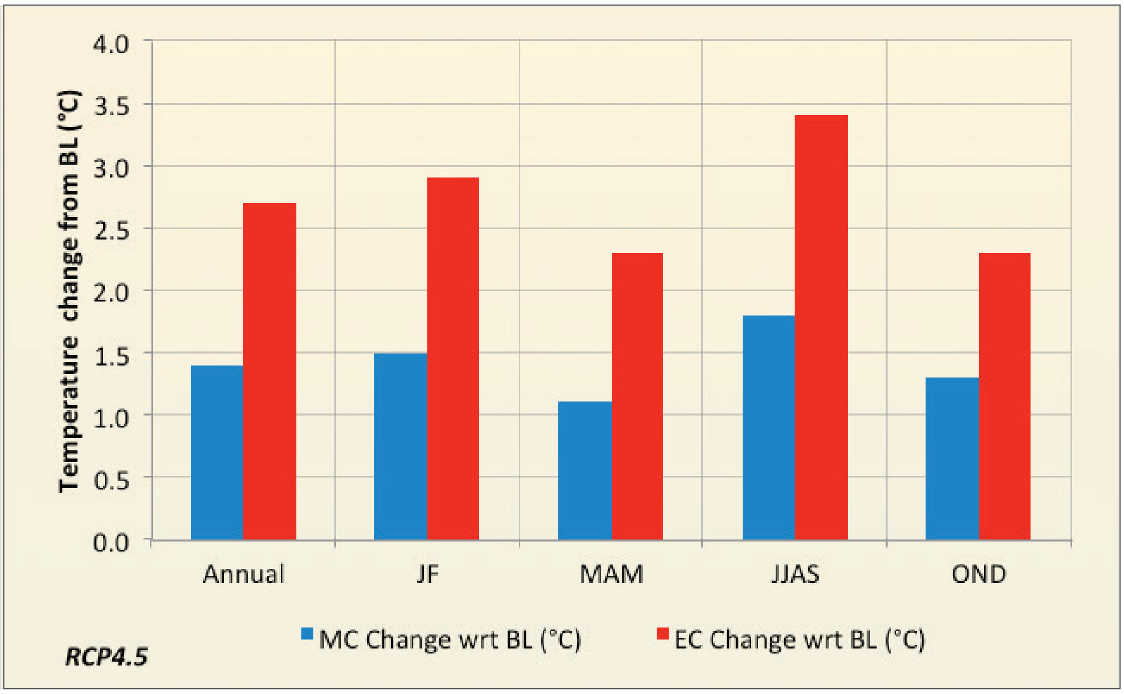


Figure 21 (c) *Characteristics of projected changes in annual and seasonal minimum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

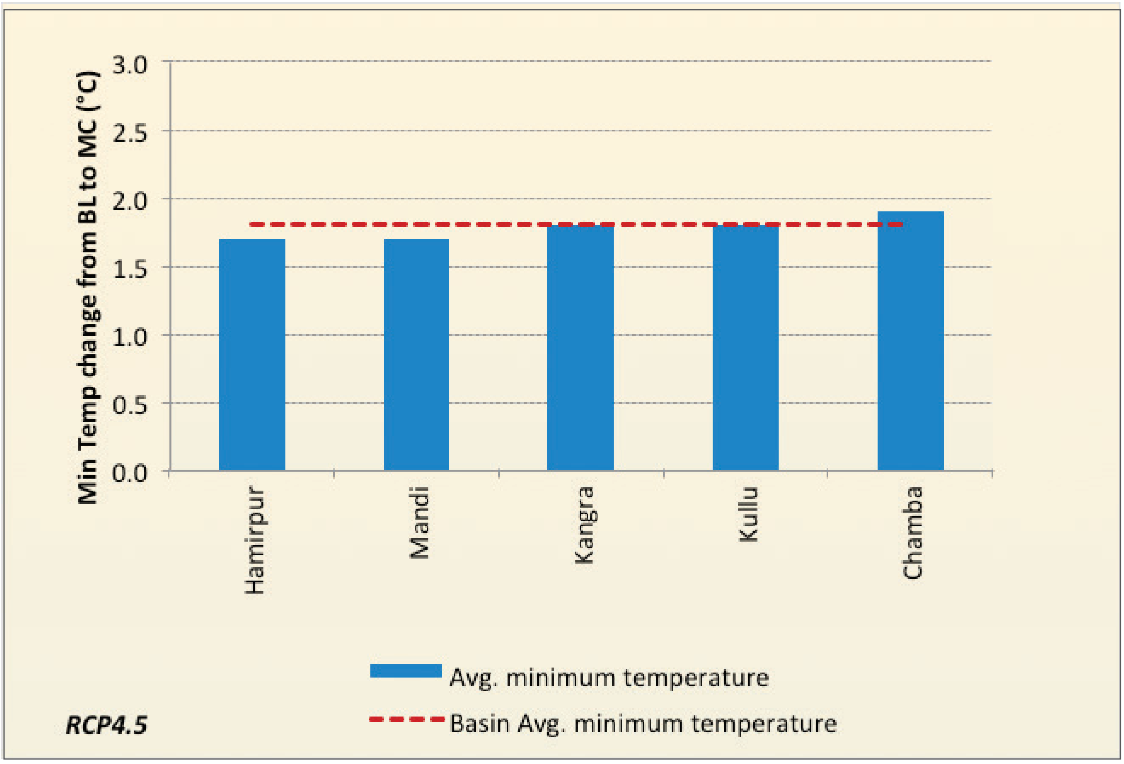


Figure 22 (a) *Characteristics of projected changes (BL to MC) in annual minimum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

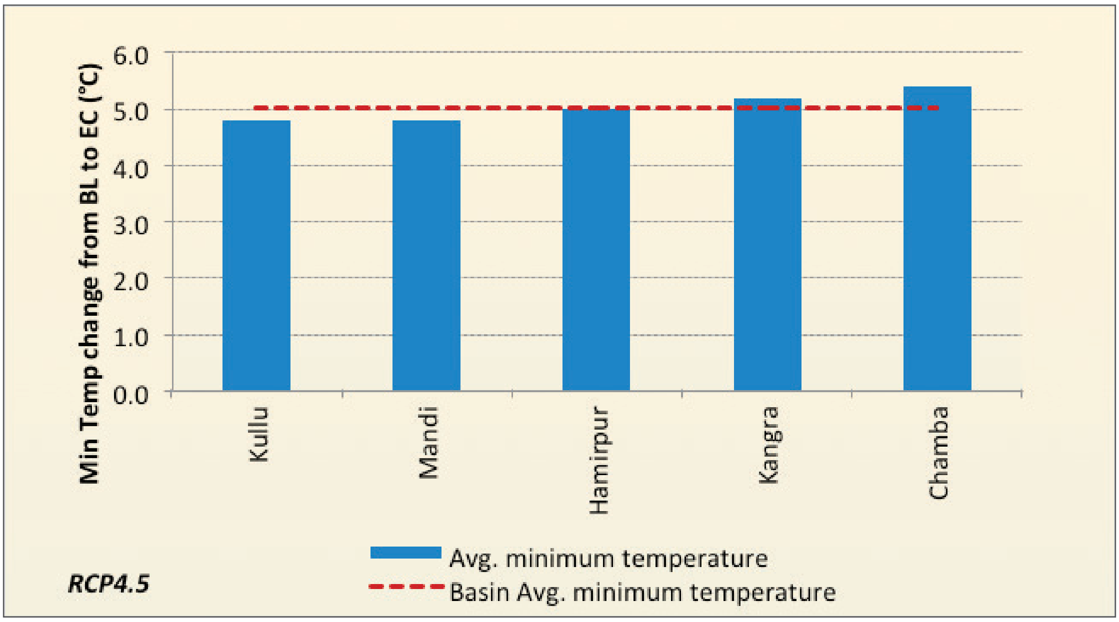


Figure 22 (b) *Characteristics of projected changes (BL to EC) in annual minimum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

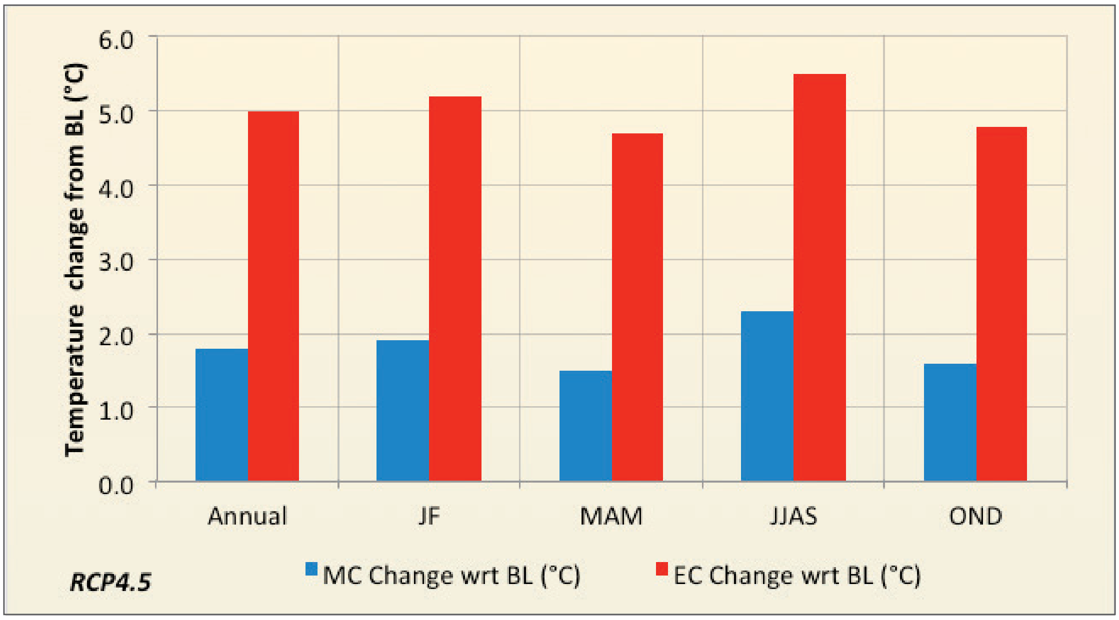


Figure 22 (c) *Characteristics of projected changes in annual and seasonal minimum temperature for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

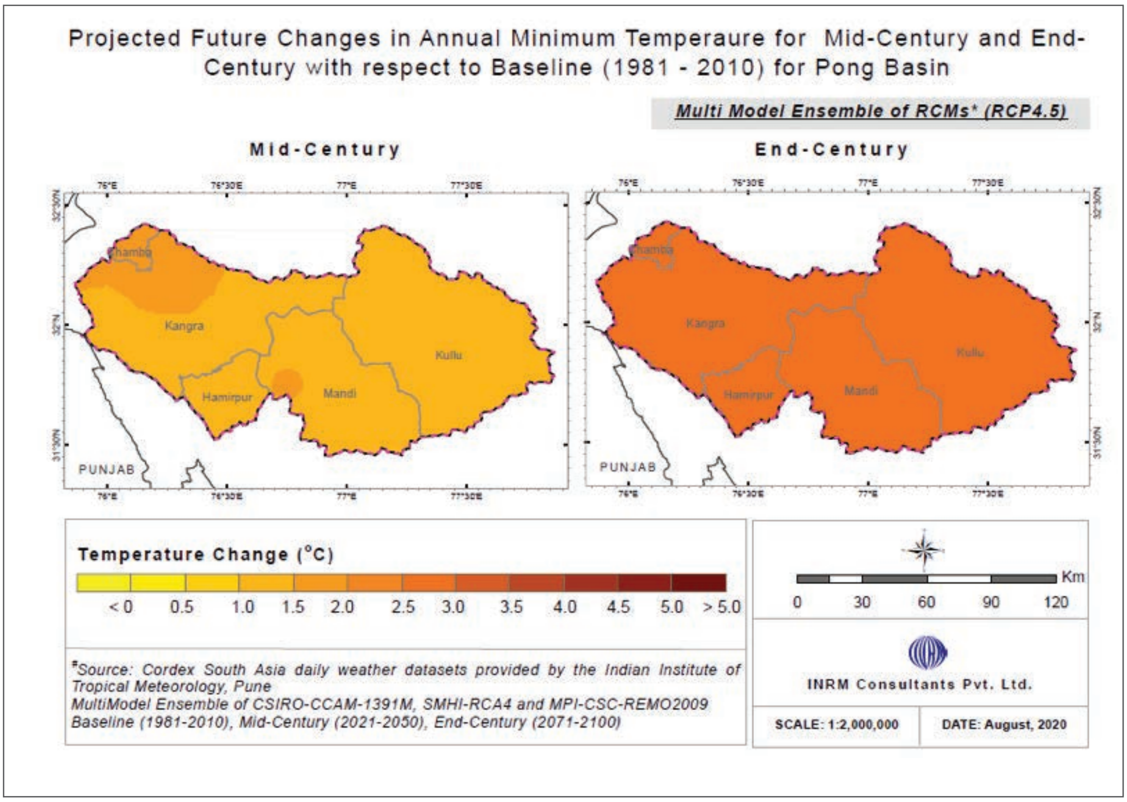


Figure 23 (a) *Spacial representation of projected changes in annual minimum temperature for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

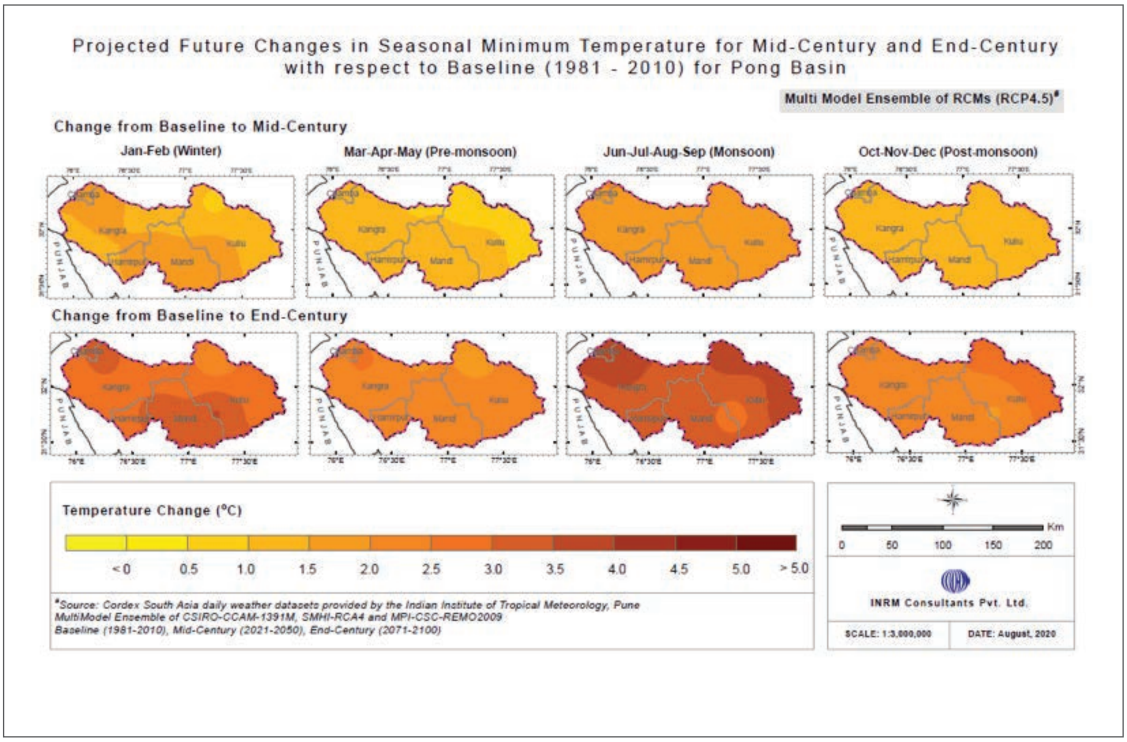


Figure 23 (b) *Spatial Representation of projected changes in seasonal minimum temperature for IPCC AR5 RCP 4.5 Scenario for Pong Dam lake basin*

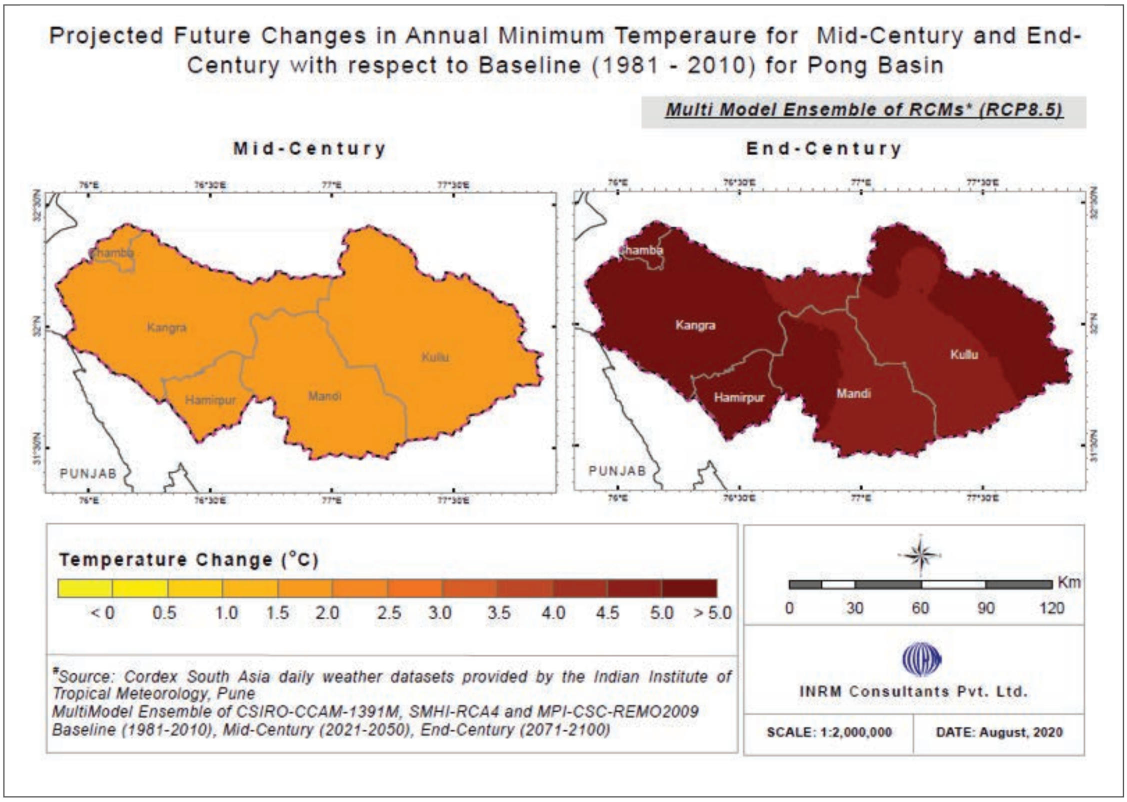


Figure 24 (a) *Spatial Representation of projected changes in annual minimum temperature for IPCC AR5 RCP 8.5 Scenario for Pong Dam lake basin*

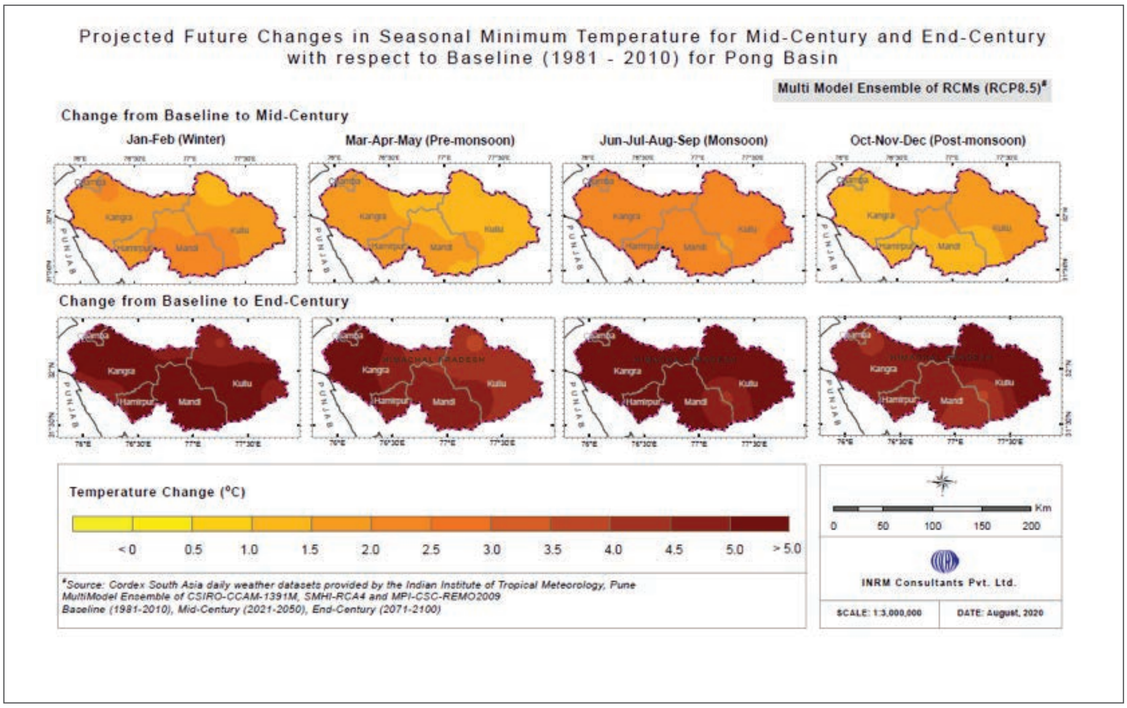


Figure 24 (b) *Spatial Representation of projected changes in seasonal minimum temperature for IPCC AR5 RCP 4.5 Scenario for Pong Dam lake basin*

PRECIPITATION PROJECTIONS FOR PONG DAM LAKE BASIN

ANALYSIS OF PROJECTED PRECIPITATION

Ensemble means of the CORDEX South Asia climate data for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios for Pong basin and districts falling in it for the annual precipitation have been analysed. The projected annual and seasonal precipitation changes towards MC and EC with respect to BL for Pong Dam lake basin and districts falling in it for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios are given in Appendix I (Table 11 and Table 12 respectively).

Figure 25 and Figure 26 show the projected percentage change in annual rainfall towards MC and EC with respect to BL for Pong basin and districts falling in it for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The same has also been depicted as a line graph for Pong Dam lake basin and as a bar graph for the districts. The seasonal changes for the Pong basin towards MC and EC as compared to BL are also shown for both IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The spatial representation of projected changes in annual and seasonal precipitation for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios is shown in Figure 27 and Figure 28 respectively.

Summary of the projected change in precipitation for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios is as follows:

- The average annual rainfall for the IPCC AR5 RCP 4.5 scenario is projected to increase by 5.6% towards MC and increase by about 11.8% towards EC, while for the IPCC AR5 RCP 8.5 scenario it is projected to increase by about 13% towards MC and by 11.7% towards EC for the basin.
- Districts in the 'very high hills' temperate dry zone of Pong basin in the south show the highest projected increase in annual rainfall among all districts of Pong basin towards EC with respect to BL for the IPCC AR5 RCP 4.5 scenario. Kullu district in the 'high hills' temperate wet zone shows the lowest projected increase towards both MC and EC (Figure 25 to Figure 28).
- Districts in the 'very high hills' temperate dry zone of Pong basin show the highest projected increase in annual rainfall (about 28%) towards EC with respect to BL for the IPCC AR5 RCP 8.5 scenario. Kullu and Chamba districts show the lowest projected increase towards both MC and EC (Figure 25 to Figure 28).
- The monsoon (June, July, August and September (JJAS)) rainfall contributes maximum to the annual rainfall amounting to approximately 57%, followed by post-monsoon season, which contributes about 18% to the annual rainfall for Pong basin. The contribution of winter and pre-monsoon season altogether is about 25%.
- In the monsoon season (JJAS) and post-monsoon season (October, November and December (OND)), rainfall increase is projected, while in winter(JF) and pre-monsoon season (MAM), rainfall decrease is projected towards MC and EC as compared to BL for Pong basin for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios (Figure 25 to Figure 28).

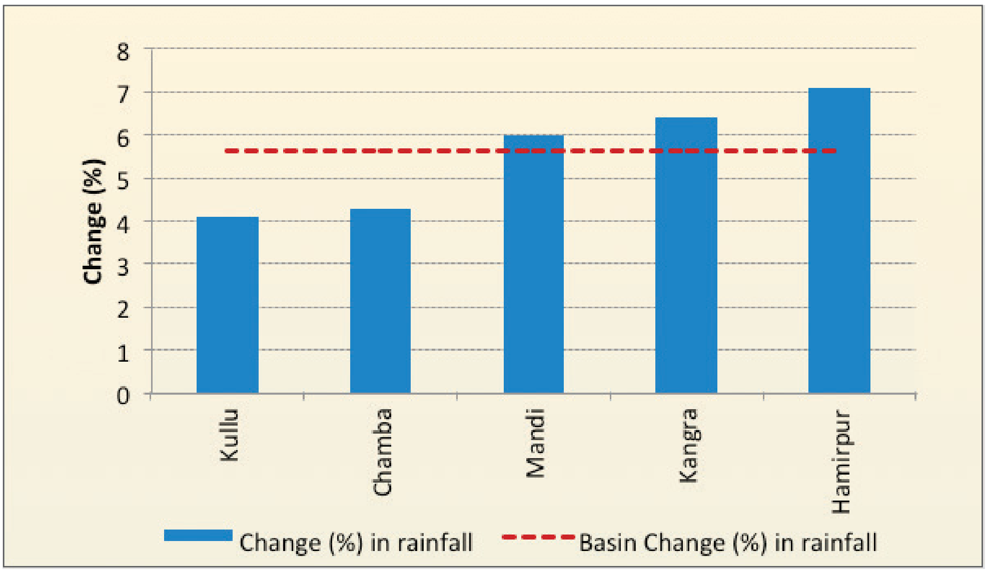


Figure 25 (a) *Characteristics of projected changes (BL to MC) in annual rainfall for IPCC AR5 RCP 4.5 Scenario for Pong Dam lake basin*

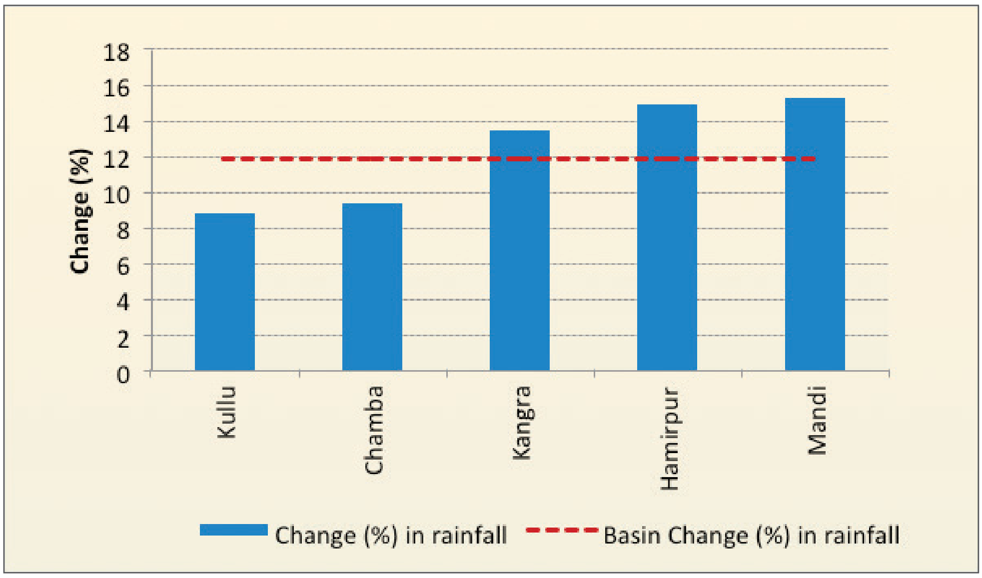


Figure 25 (b) *Characteristics of projected changes (BL to EC) in annual rainfall for IPCC AR5 RCP 4.5 Scenario for Pong Dam lake basin*

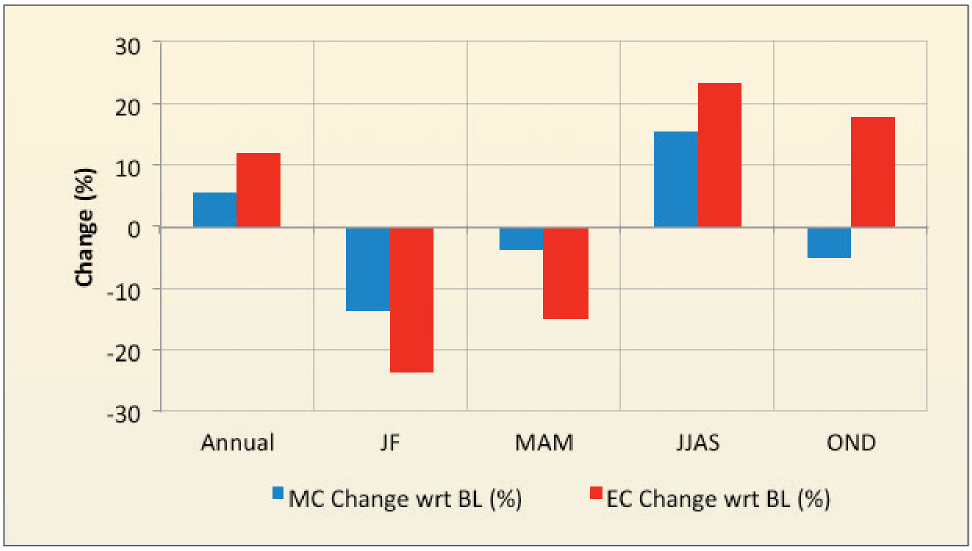


Figure 25 (c) *Characteristics of projected changes in annual and seasonal rainfall for IPCC AR5 RCP 4.5 Scenario for Pong Dam lake basin*

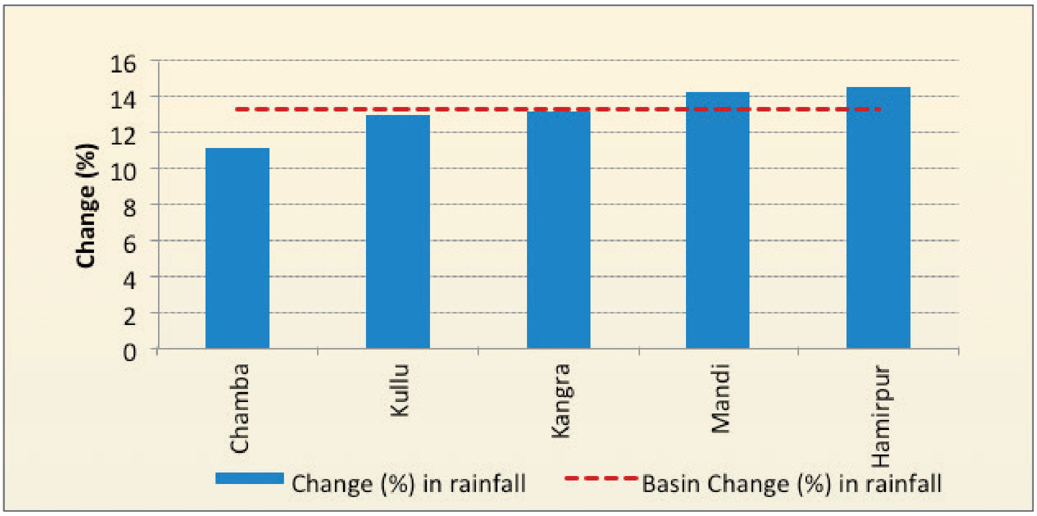


Figure 26 (a) *Characteristics of projected changes (BL to MC) in annual rainfall for IPCC AR5 RCP 8.5 Scenario for Pong Dam lake basin*

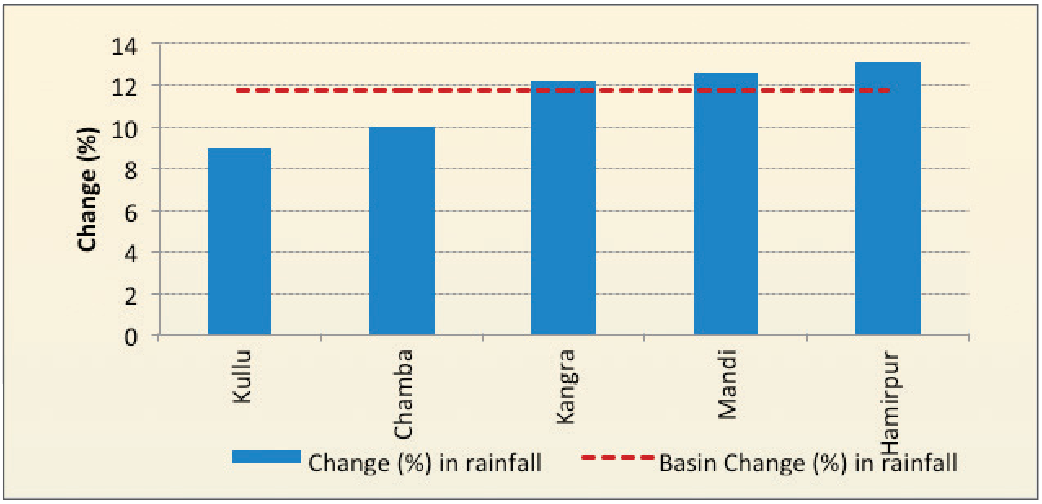


Figure 26 (b) *Characteristics of projected changes (BL to EC) in annual rainfall for IPCC AR5 RCP 8.5 Scenario for Pong Dam lake basin*

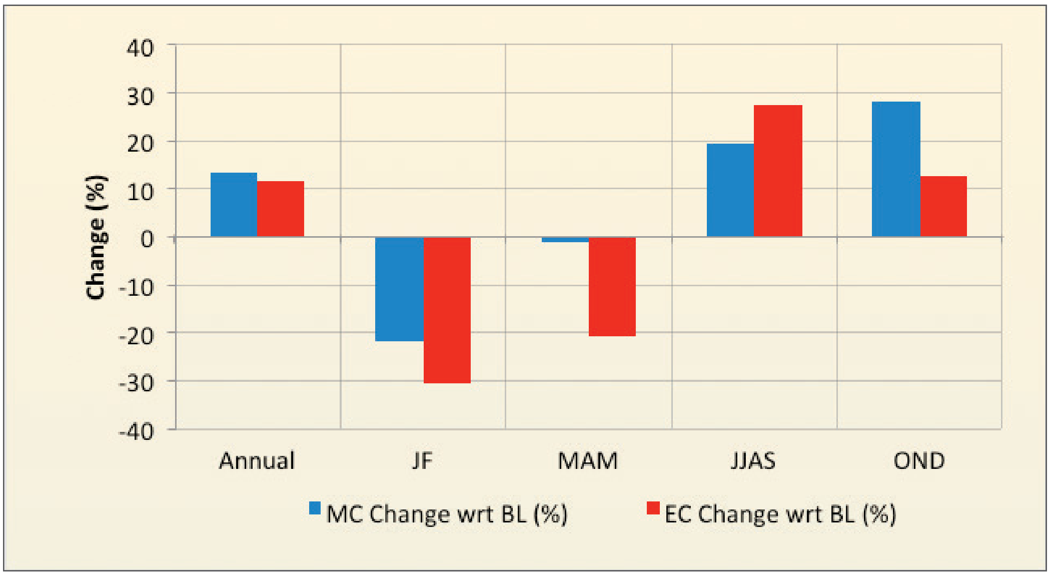


Figure 26 (c) *Characteristics of projected changes in annual and seasonal rainfall for IPCC AR5 RCP 8.5 Scenario for Pong Dam lake basin*

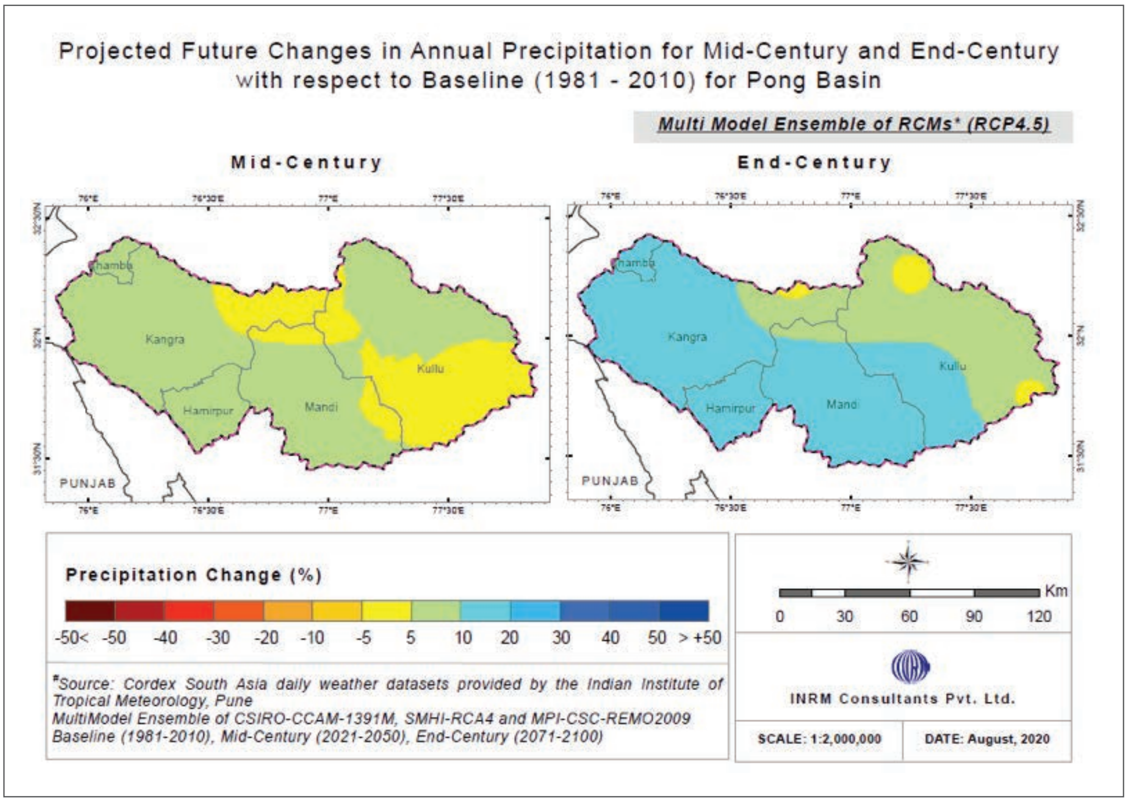


Figure 27 (a) *Spatial representation of projected changes in annual precipitation for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

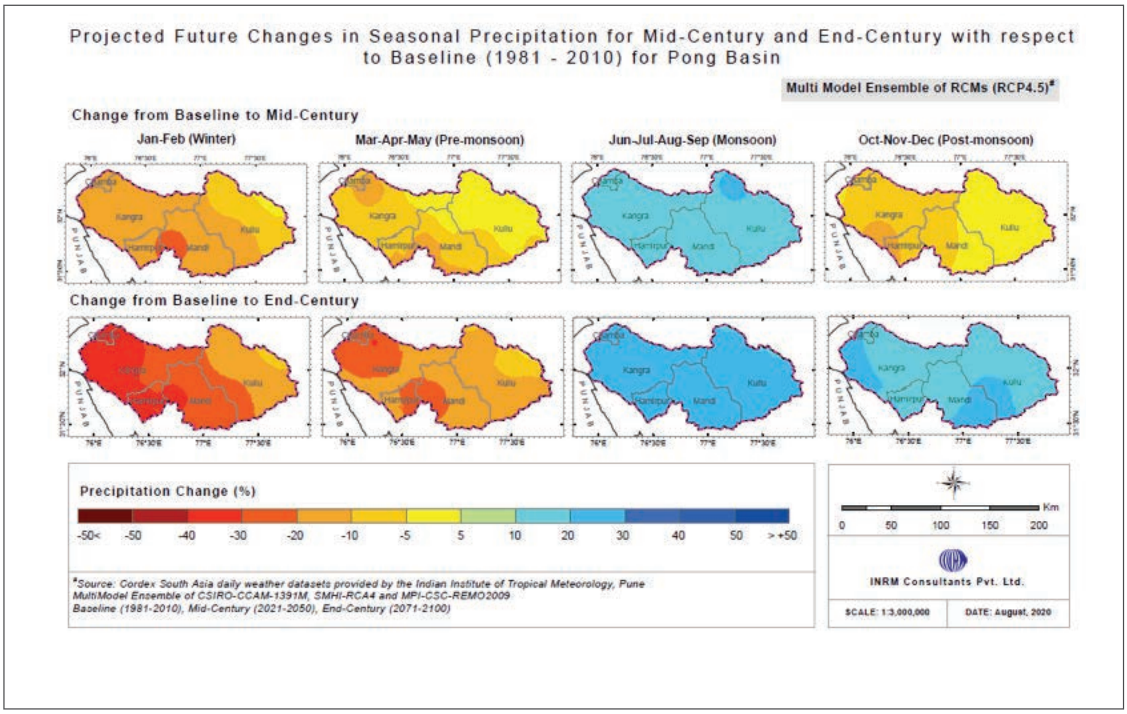


Figure 27 (b) *Spatial representation of projected changes in annual and seasonal precipitation for IPCC AR5 RCP 4.5 scenario for Pong Dam lake basin*

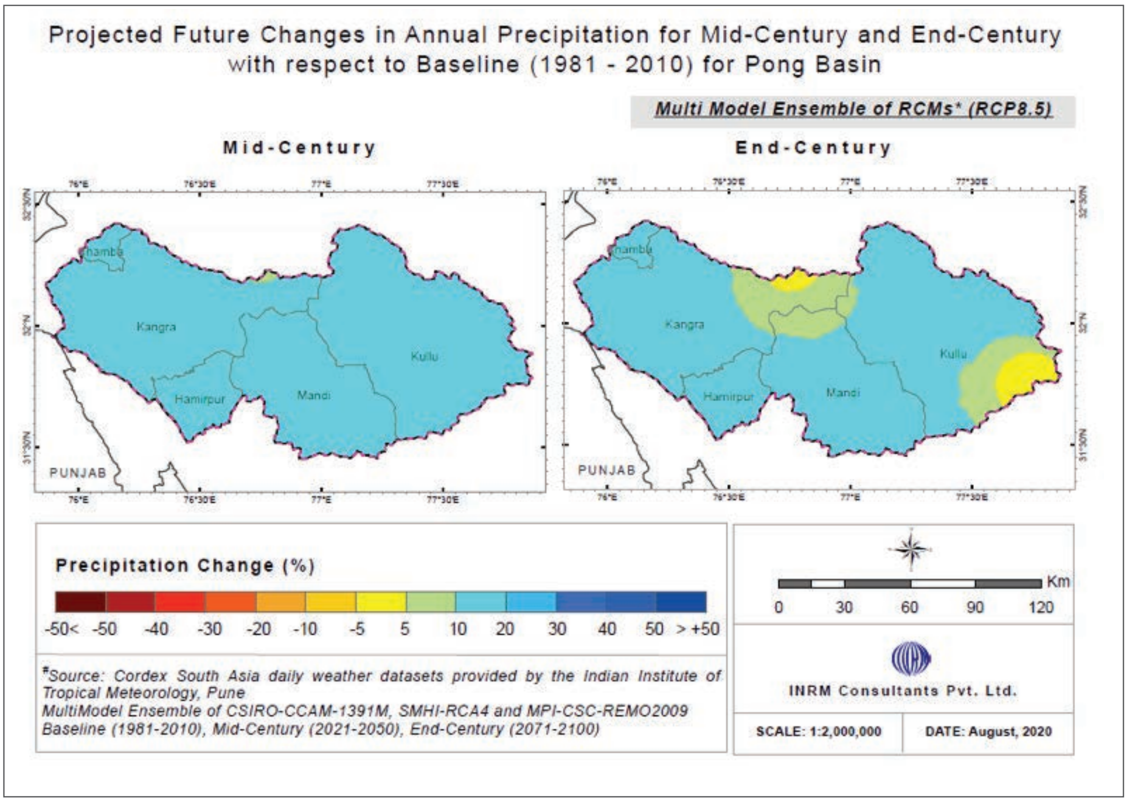


Figure 28 (a) *Spatial representation of projected changes in annual precipitation for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

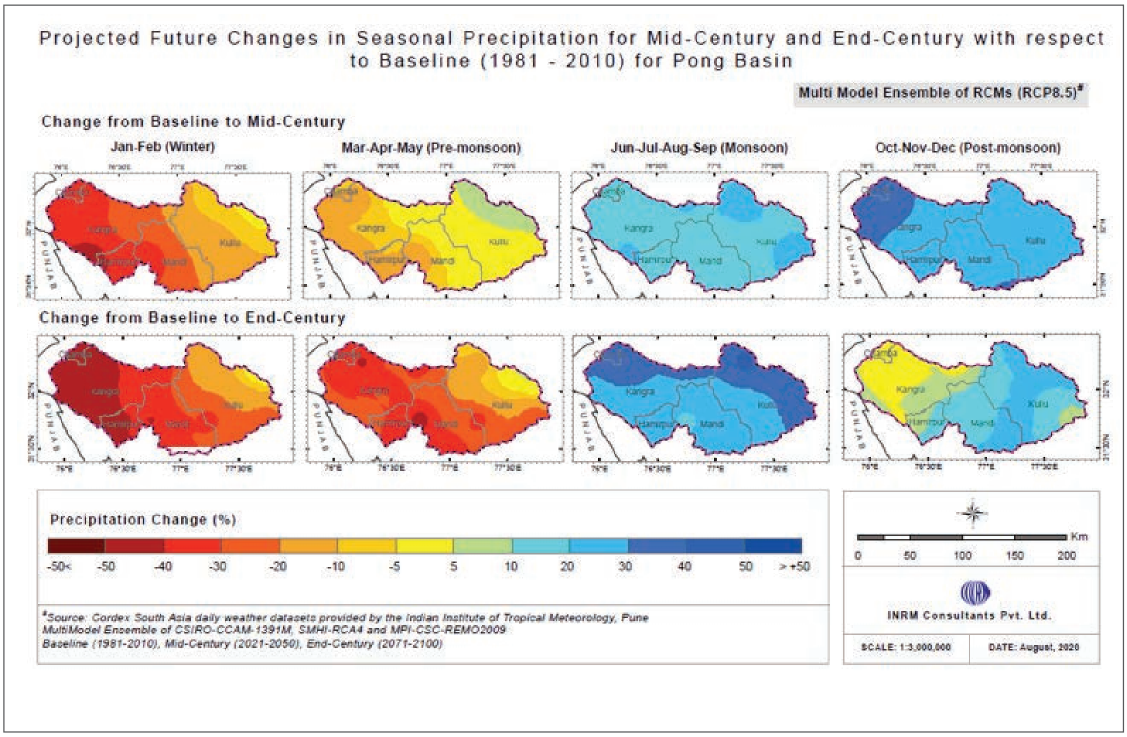


Figure 28 (b) *Spatial representation of projected changes in annual and seasonal precipitation for IPCC AR5 RCP 8.5 scenario for Pong Dam lake basin*

CLIMATE INDICES

TEMPERATURE EXTREME INDICES

Most temperature extreme indices show trends consistent with warming during the period of analysis. The temperature extreme indices graphs showing change towards MC and EC with respect to BL are shown in Figure 29 and Figure 30, and description of the parameters is given in Appendix I (Table 13). The results for temperature extremes indices of Pong Dam lake basin are summarized as follows:

Absolute indices: Maximum of daytime temperature (TXx), maximum of night-time temperature (TNx),minimum of daytime temperature (TXn) and minimum of night-time temperature (TNn) values towards MC and EC are higher compared to BL for both the climate scenarios, implying that the temperature is projected to increase for the districts of Pong Dam lake basin resulting in overall warming-up. The variation across the districts can be seen in Figure 29.

Percentile indices: For IPCC AR5 RCP4.5 and RCP8.5 scenarios, the percentage of cool nights (TN10P) and cool days (TX10P) is projected to decrease, while the percentage of warm nights (TN90P) and warm days (TX90P) is projected to increase towards MC and EC as compared to BL for all the districts. Decrease (cool days and cool nights)/increase (warm days and warm nights) in frequency of these indices towards EC is higher than that of MC, which implies higher warming towards EC than MC (Figure 31).

Duration indices: The cold spell duration indicator (CSDI) is projected to decrease, and warm spell duration indicator (WSDI) is projected to increase, for all the districts towards MC and EC compared to BL, implying warming-up over Pong basin districts. The variation across the districts can be seen in Figure 31.

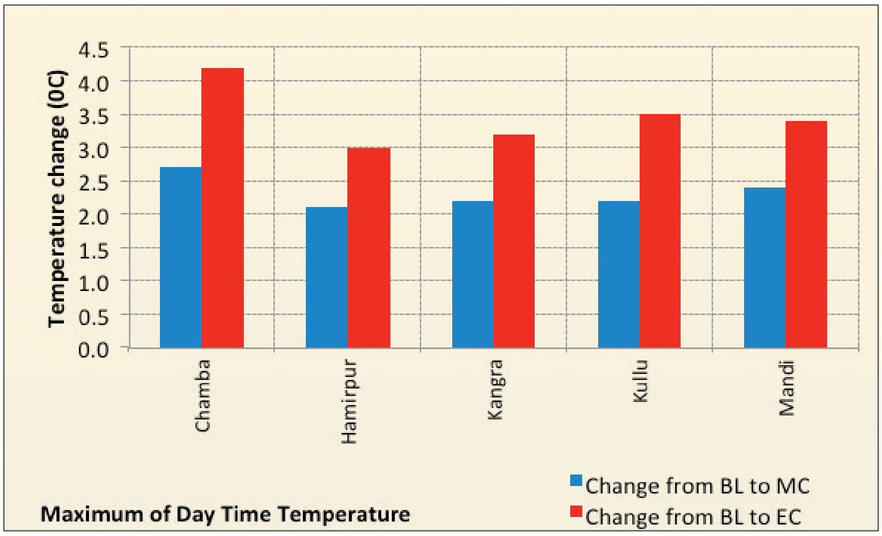


Figure 29 (a) *Characteristic of projected changes in maximum of daytime temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

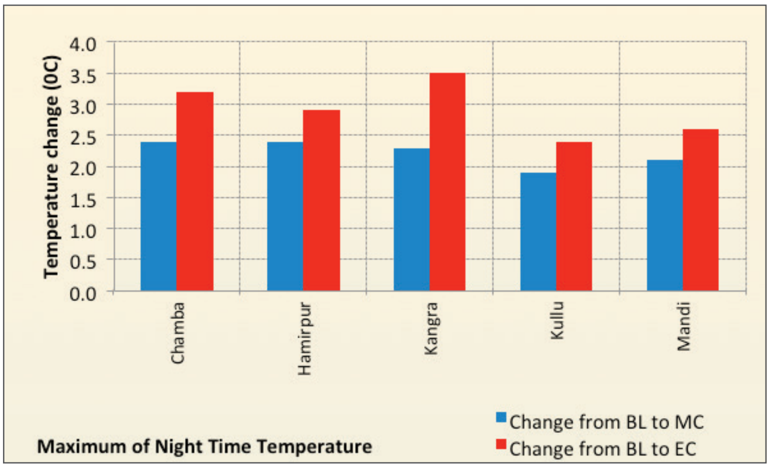


Figure 29 (b) *Characteristic of projected changes in maximum of night time temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

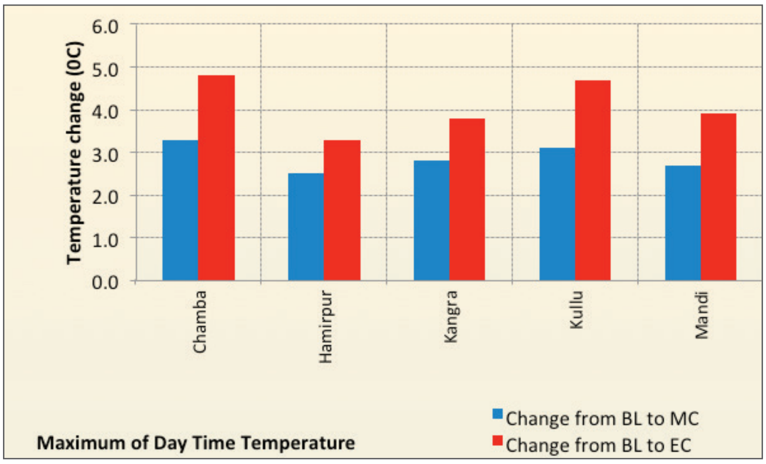


Figure 29 (c) *Characteristic of projected changes in minimum of daytime temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

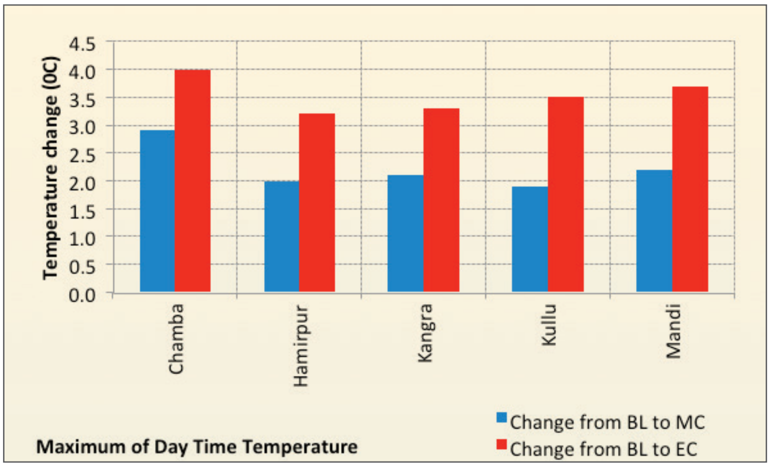


Figure 29 (d) *Characteristic of projected changes in minimum of night time temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

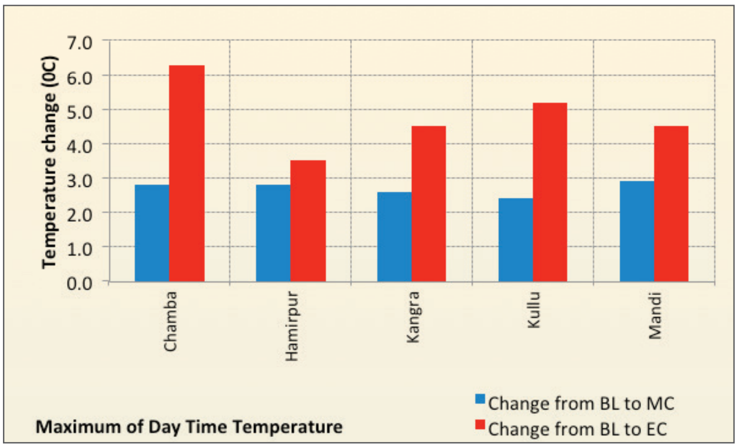


Figure 29 (e) *Characteristic of projected changes in maximum of daytime temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

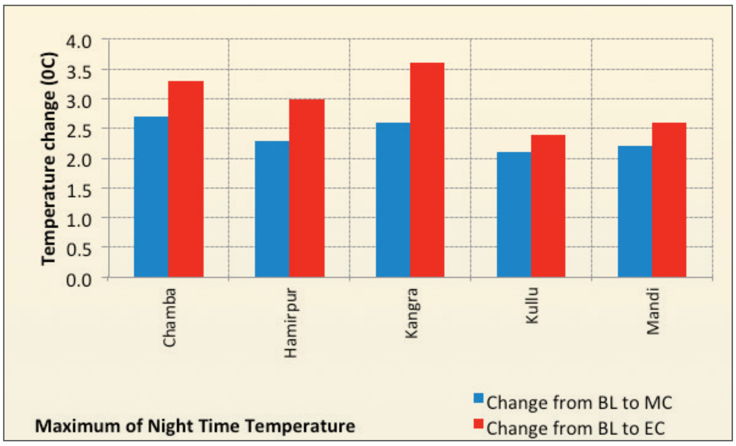


Figure 29 (f) *Characteristic of projected changes in maximum of night time temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

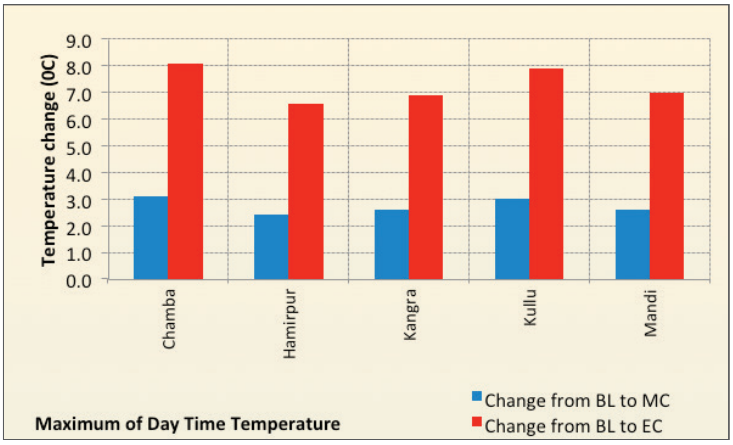


Figure 29 (g) *Characteristic of projected changes in minimum of daytime temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

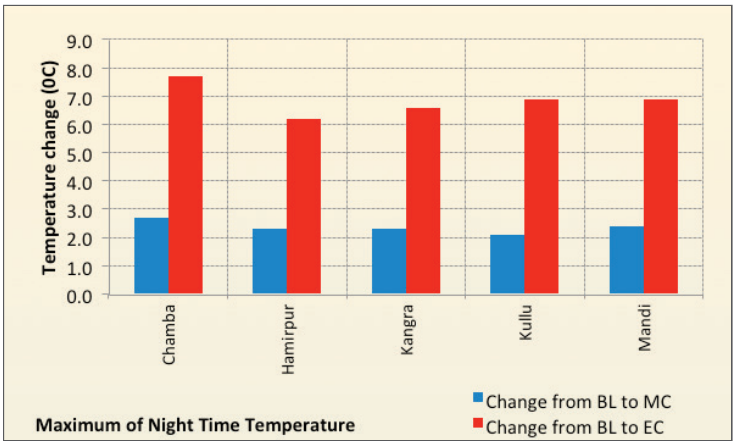


Figure 29 (h) *Characteristic of projected changes in maximum of night time temperature for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

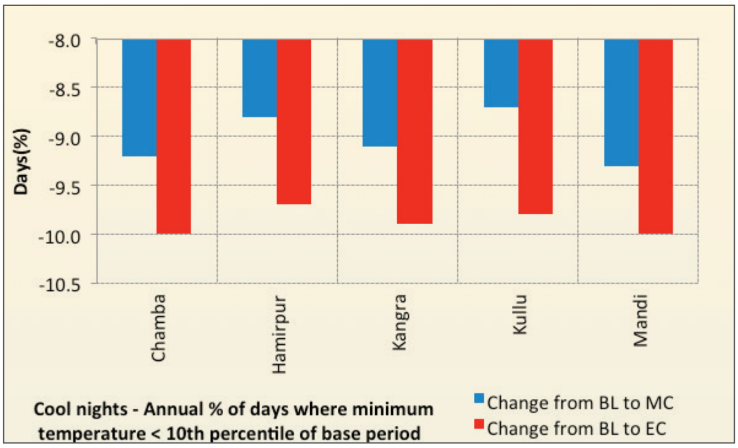


Figure 30 (a) *Characteristic of projected changes in percentage of cool nights for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

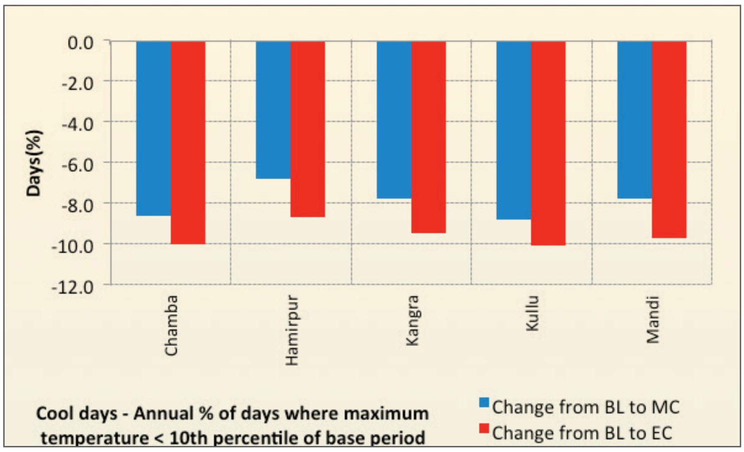


Figure 30 (b) *Characteristic of projected changes in percentage of cool days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

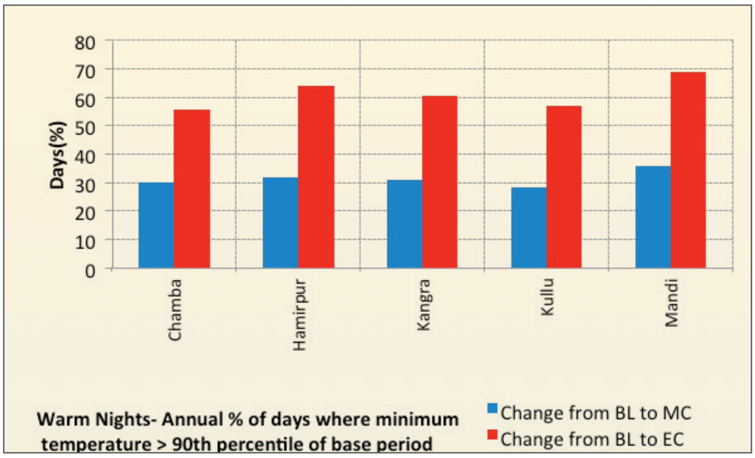


Figure 30 (c) *Characteristic of projected changes in percentage of warm nights for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

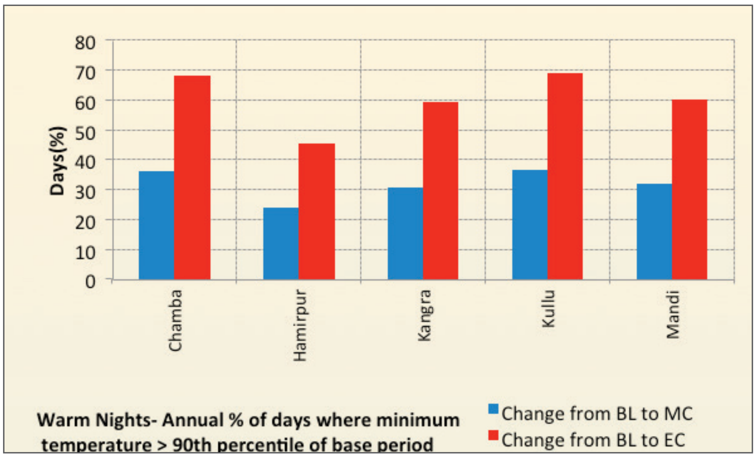


Figure 30 (d) *Characteristic of projected changes in percentage of warm nights for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

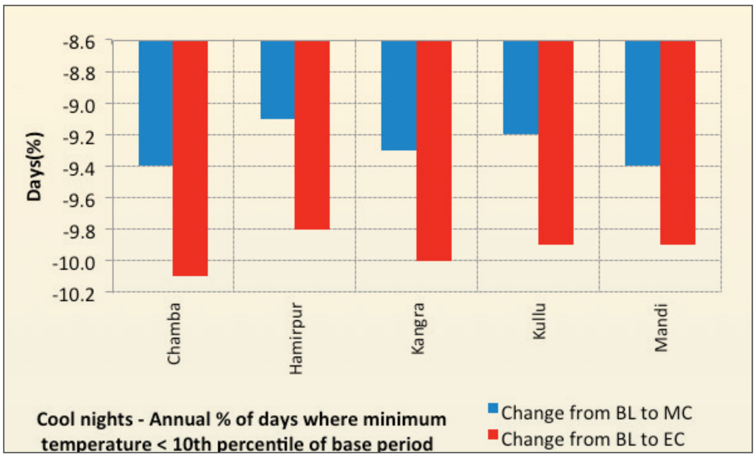


Figure 30 (e) *Characteristic of projected changes in percentage of cool nights for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

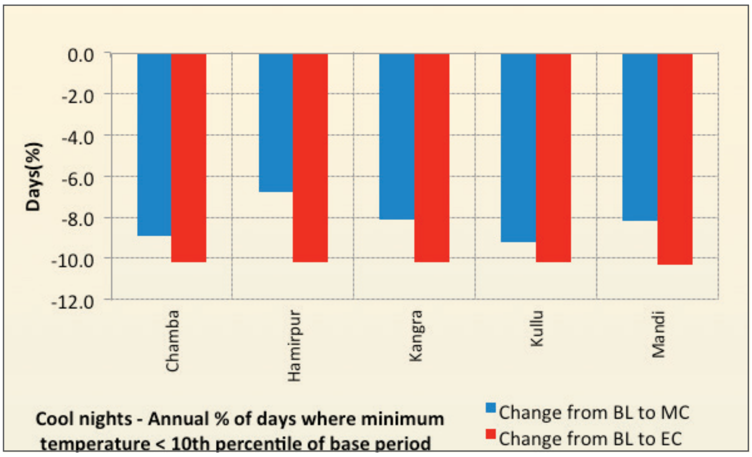


Figure 30 (f) *Characteristic of projected changes in percentage of cool days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

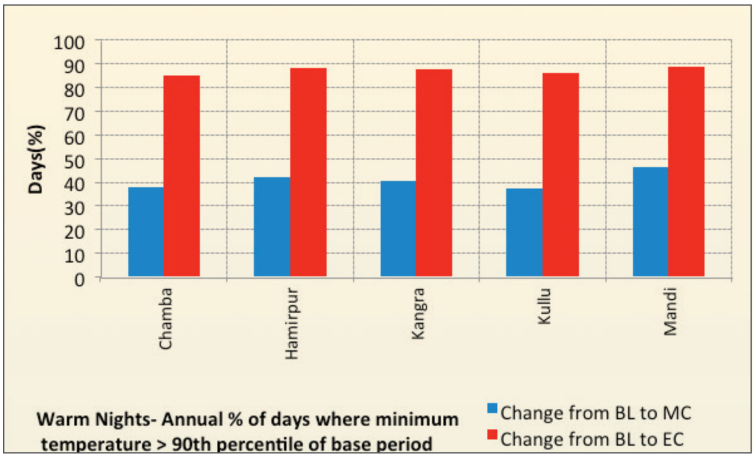


Figure 30 (g) *Characteristic of projected changes in percentage of warm nights for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

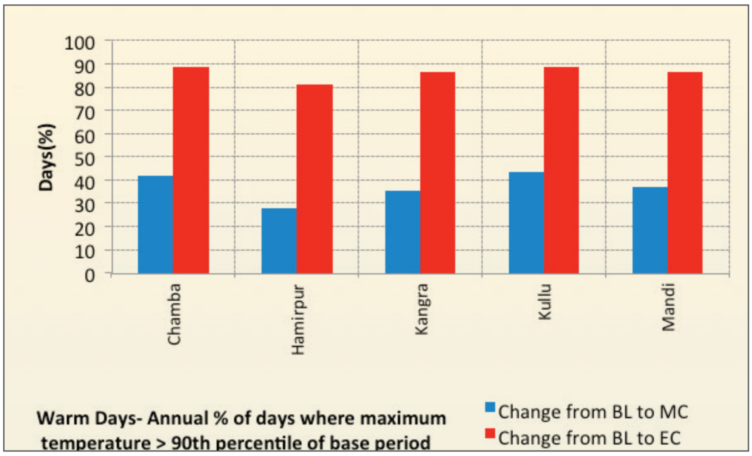


Figure 30 (h) *Characteristic of projected changes in percentage of warm days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

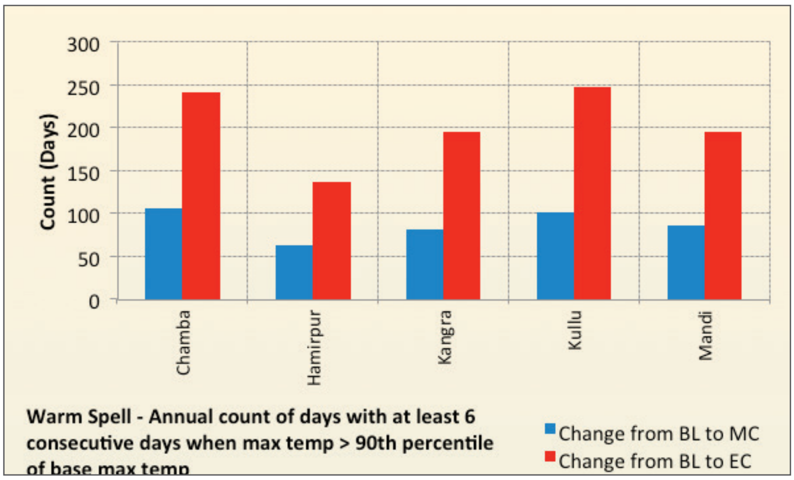


Figure 31 (a) *Characteristic of projected changes in percentage of warm spells for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

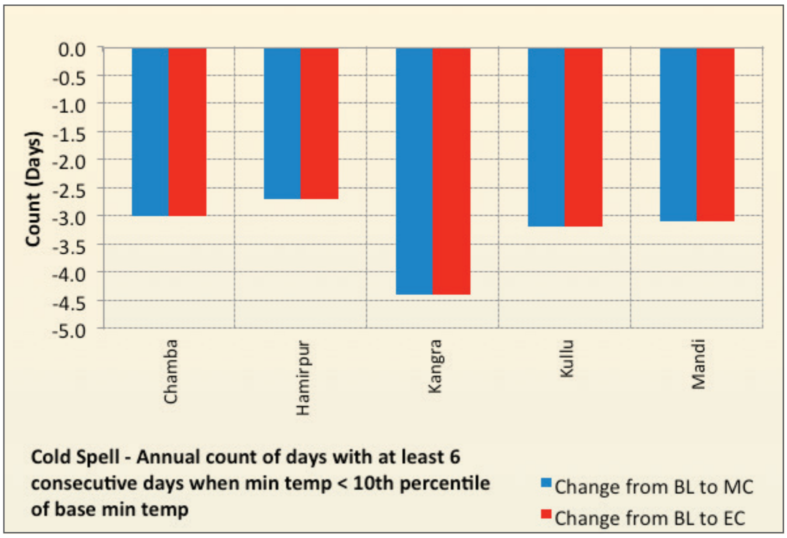


Figure 31 (b) *Characteristic of projected changes in percentage of cold spells for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

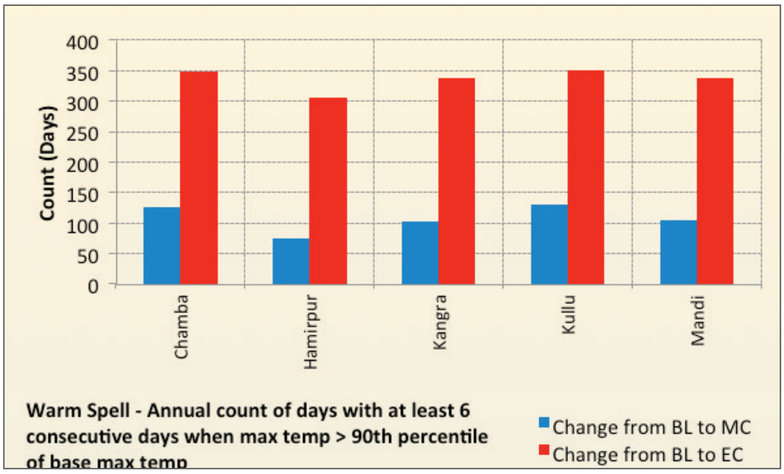


Figure 31 (c) *Characteristic of projected changes in percentage of warm spells for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

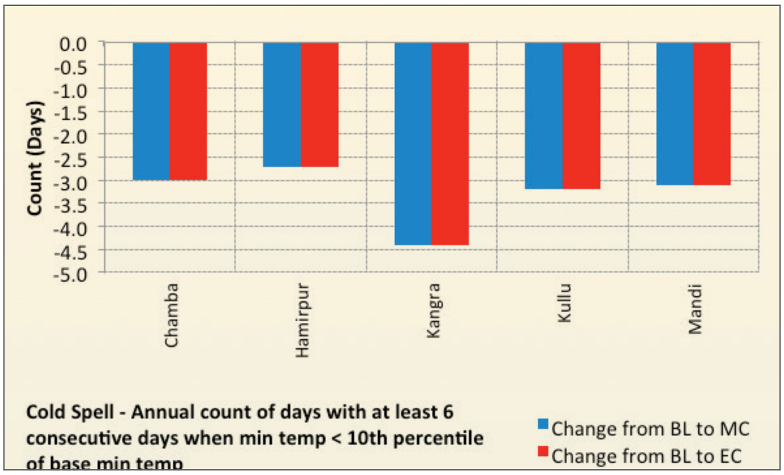


Figure 31 (d) *Characteristic of projected changes in percentage of cold spells for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

PRECIPITATION EXTREME INDICES

Rainfall and intensity of rainfall are projected to increase towards MC and EC for Pong Dam lake basin. The scenario towards MC and EC is projected to change as compared to BL scenario. The precipitation extremes indices graphs showing change towards MC and EC with respect to BL average values are shown in Figure 32 to Figure 36, and description of the parameters is given in Appendix I. The results for precipitation extremes indices of Pong basin are summarized as follows:

Absolute indices: However, 1-day maximum precipitation and 5-day maximum precipitation are projected to increase for majority of the districts towards MC and EC compared to BL, implying that rainfall intensity would increase in the future for the districts. Towards EC, increase is projected to be the highest for Kullu and Lahul & Spiti districts as compared to the baseline for RCP 8.5 climate scenario (Figure 32).

Percentile indices: Very wet days precipitation and extremely wet days precipitation are projected to increase towards MC and EC compared to BL for all the districts, for both the IPCC AR5 climate scenarios implying that rainfall intensity would increase in the future for the Pong Dam lake basin (Figure 33).

Duration indices: Consecutive dry days and consecutive wet days are projected to increase for the districts towards MC and EC as compared to BL, for both the IPCC AR5 climate scenarios. The variation across the districts can be seen in Figure 34.

Threshold indices: Heavy precipitation days and very heavy precipitation days (R10mm and R20mm) are projected to increase for all the districts of the basin towards MC and EC as compared to BL for both the IPCC AR5 climate scenarios. The increase is projected to be the highest for Hamirpur and Kangra districts (Figure 35).

Other indices: Annual precipitation and the average precipitation on wet days (Simple Daily Intensity Index) are projected to increase towards MC and EC as compared to BL for all the districts for the IPCC AR5 RCP4.5 and RCP 8.5 scenarios. Increase in rainfall intensity is projected to be the highest for Hamirpur and Kangra districts (Figure 36).

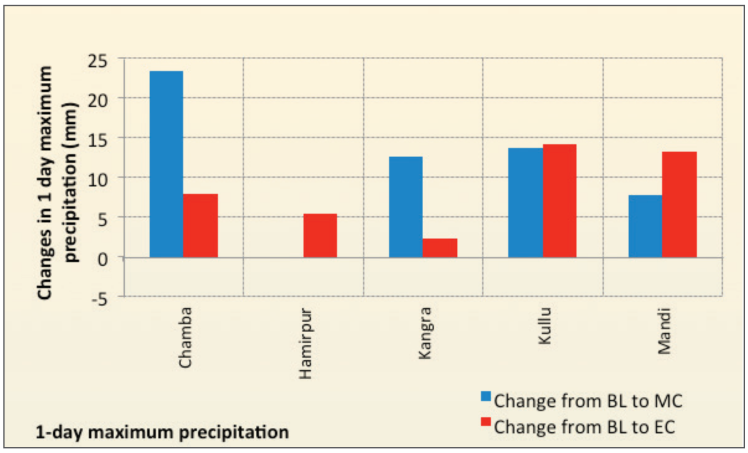


Figure 32 (a) *Characteristic of projected changes in one day maximum precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

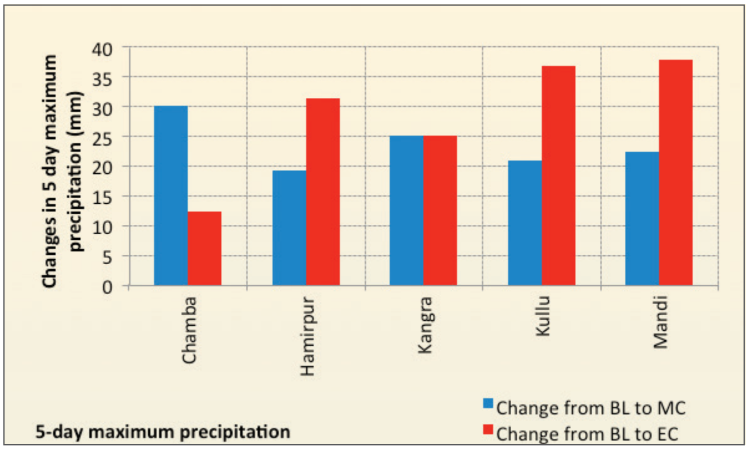


Figure 32 (b) *Characteristic of projected changes in five day maximum precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

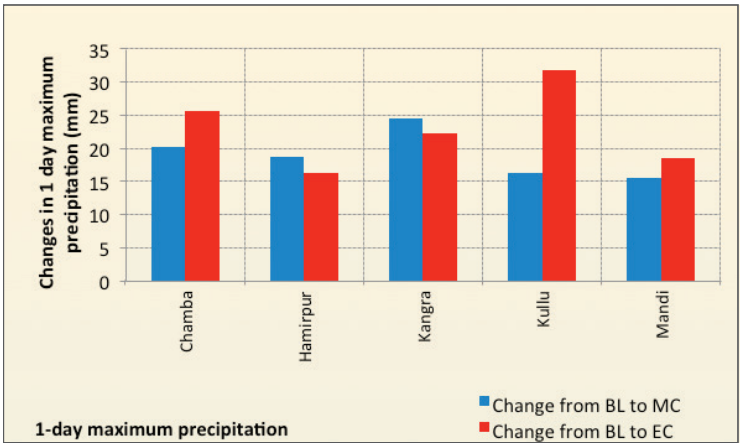


Figure 32 (c) *Characteristic of projected changes in one day maximum precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

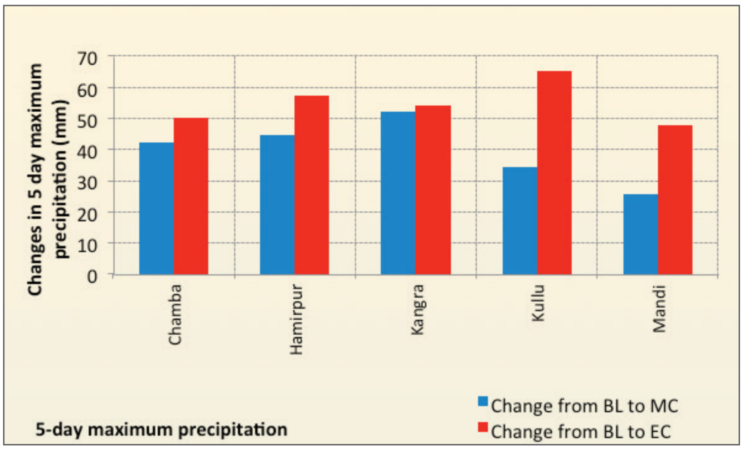


Figure 32 (b) *Characteristic of projected changes in five day maximum precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

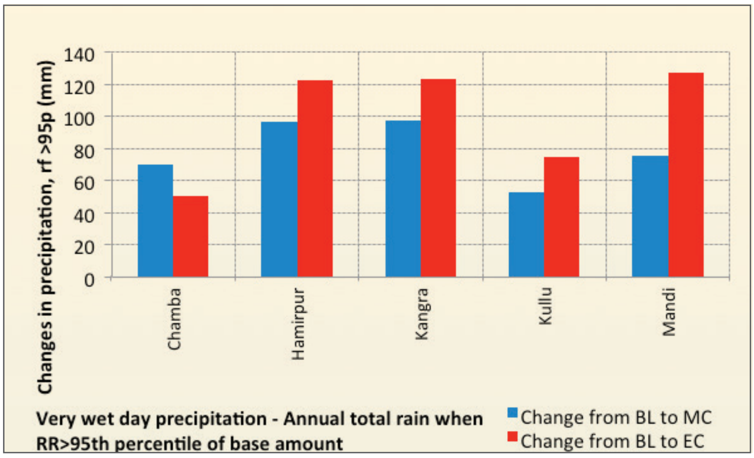


Figure 33 (a) *Characteristic of projected changes in very wet day precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

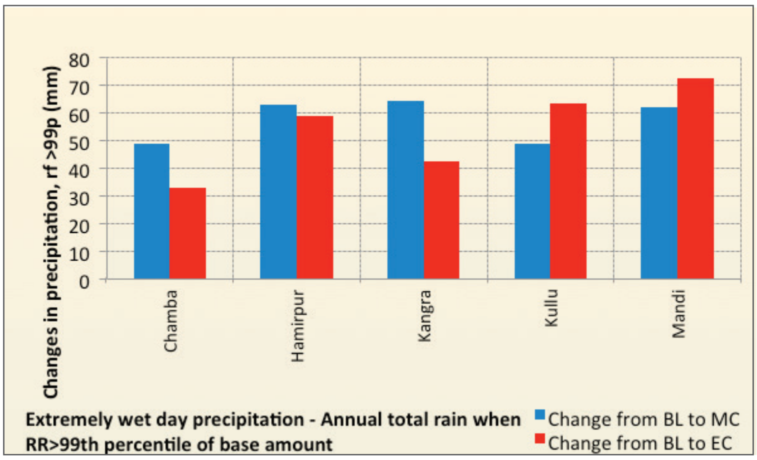


Figure 33 (b) *Characteristic of projected changes in extremely wet day precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

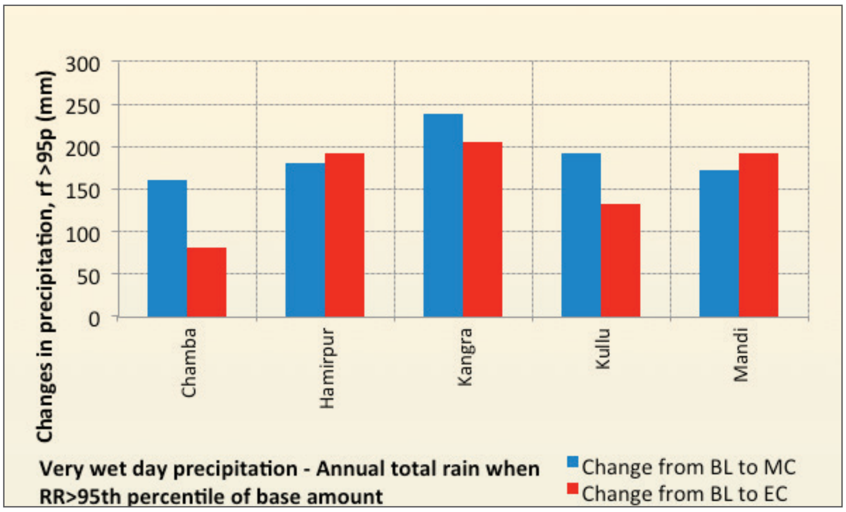


Figure 33 (c) *Characteristic of projected changes in very wet day precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 5.5 scenario)*

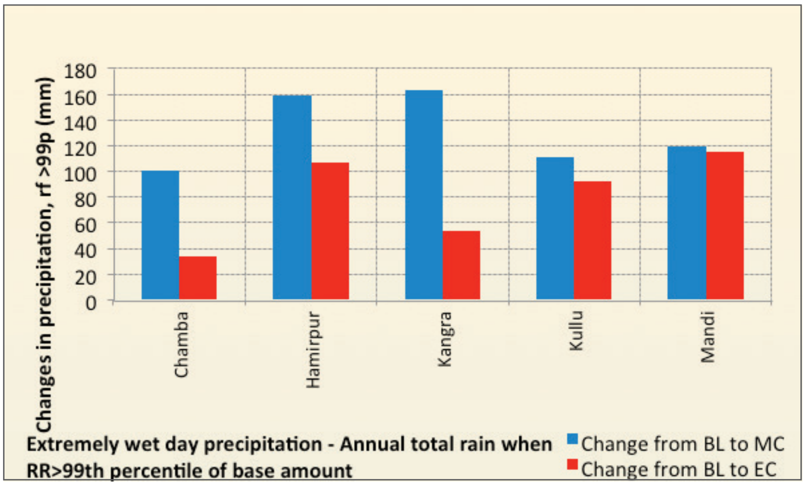


Figure 33 (d) *Characteristic of projected changes in extremely wet day precipitation for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

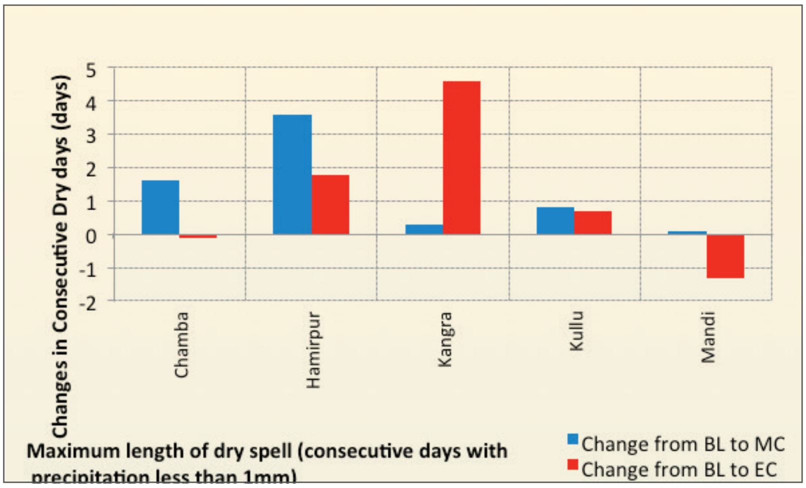


Figure 34 (a) *Characteristic of projected changes in maximum length of dry spells for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

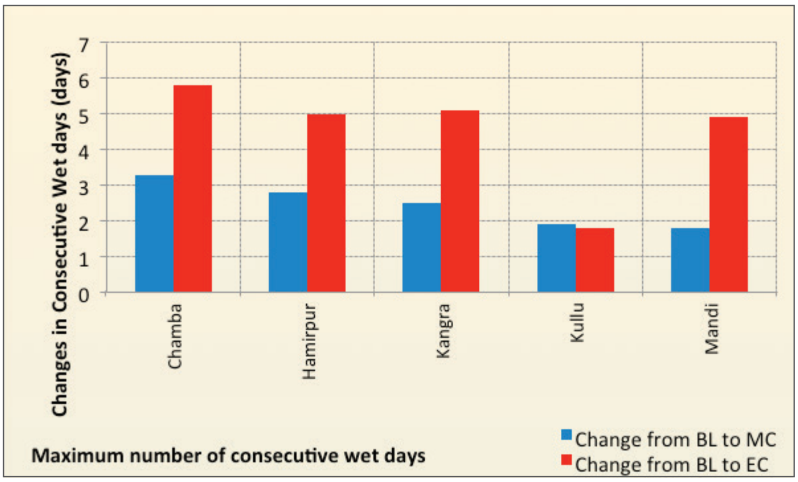


Figure 34 (b) *Characteristic of projected changes in maximum number of consecutive wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

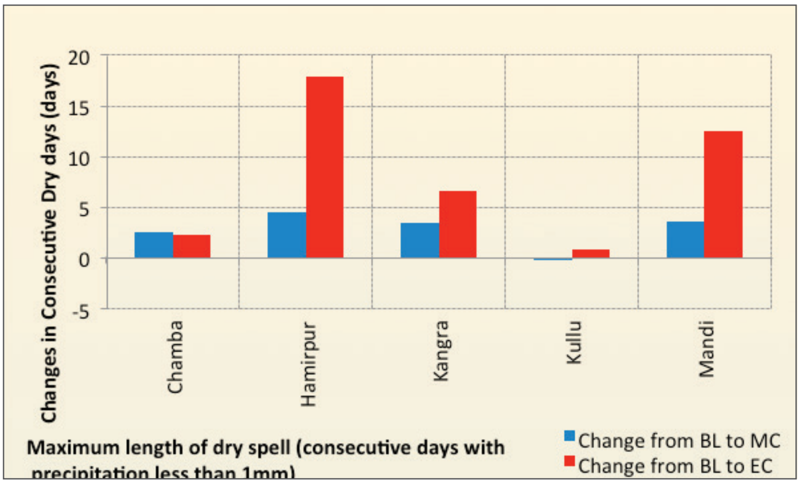


Figure 34 (c) *Characteristic of projected changes in maximum length of dry spells for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

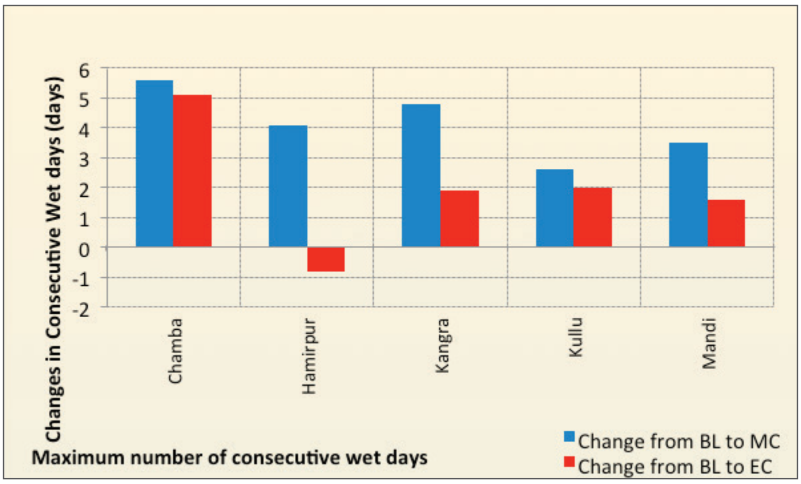


Figure 34 (d) *Characteristic of projected changes in maximum number of consecutive wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

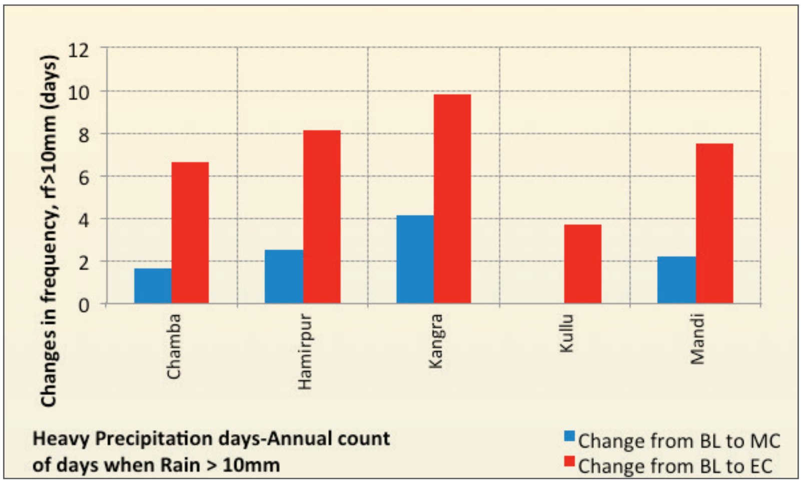


Figure 35 (a) *Characteristic of projected changes in heavy precipitation days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

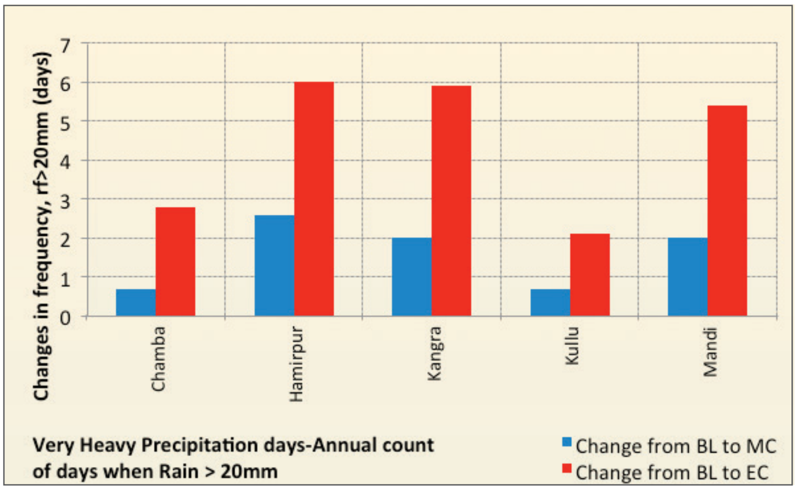


Figure 35 (b) *Characteristic of projected changes in very heavy precipitation days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

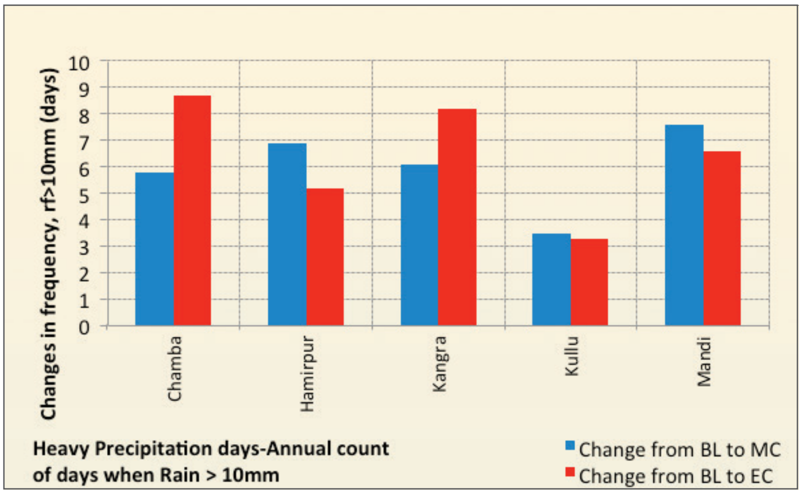


Figure 35 (c) *Characteristic of projected changes in heavy precipitation days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

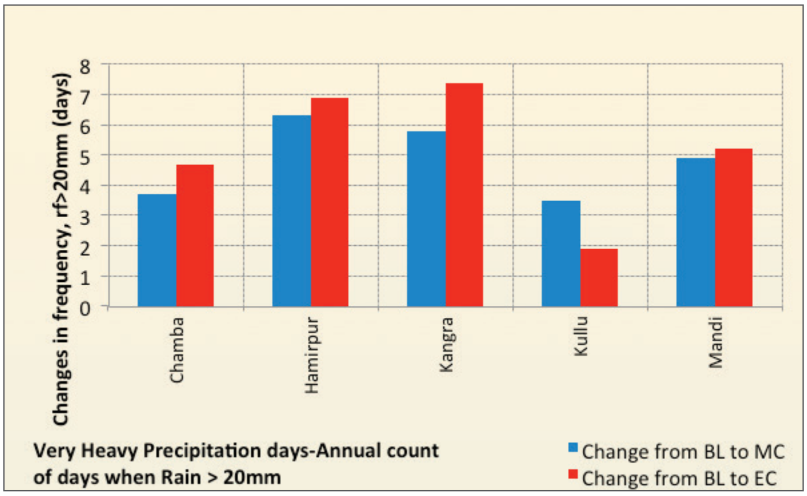


Figure 35 (d) *Characteristic of projected changes in very heavy precipitation days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

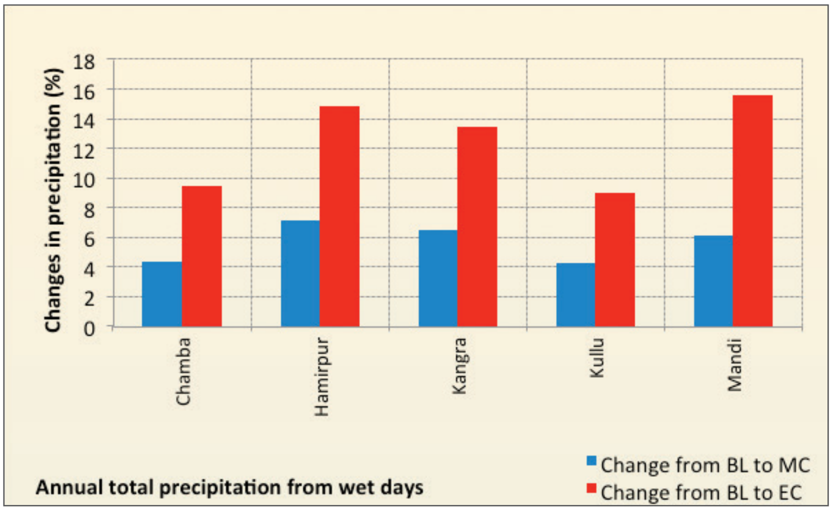


Figure 36 (a) *Characteristic of projected changes in annual total precipitation from wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

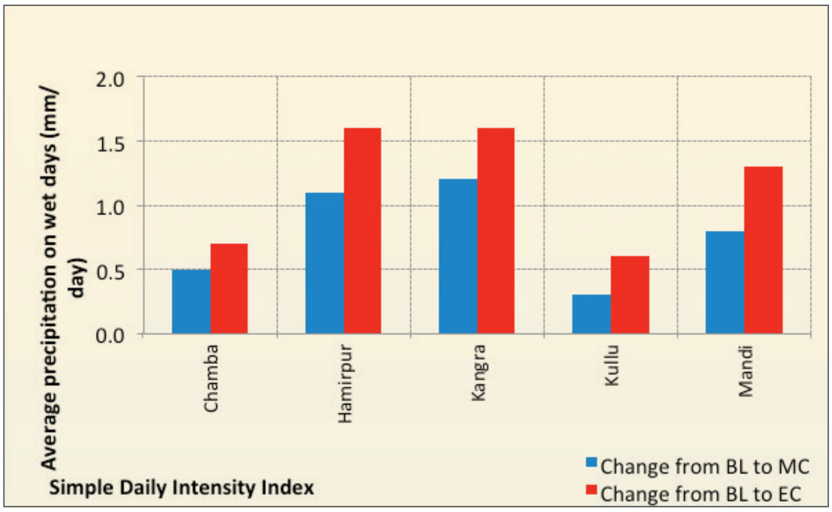


Figure 36 (b) *Characteristic of projected changes in average precipitation on wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 4.5 scenario)*

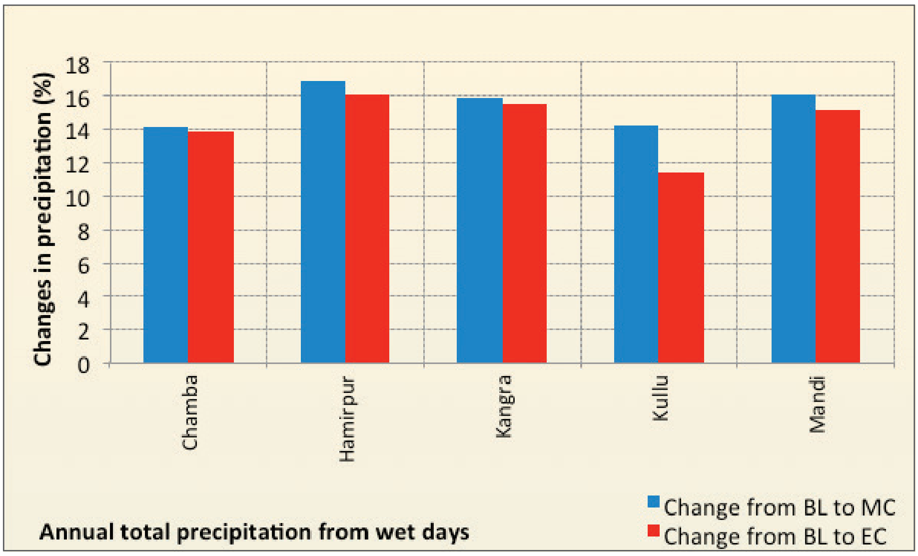


***Figure 36 (c)** Characteristic of projected changes in annual total precipitation from wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

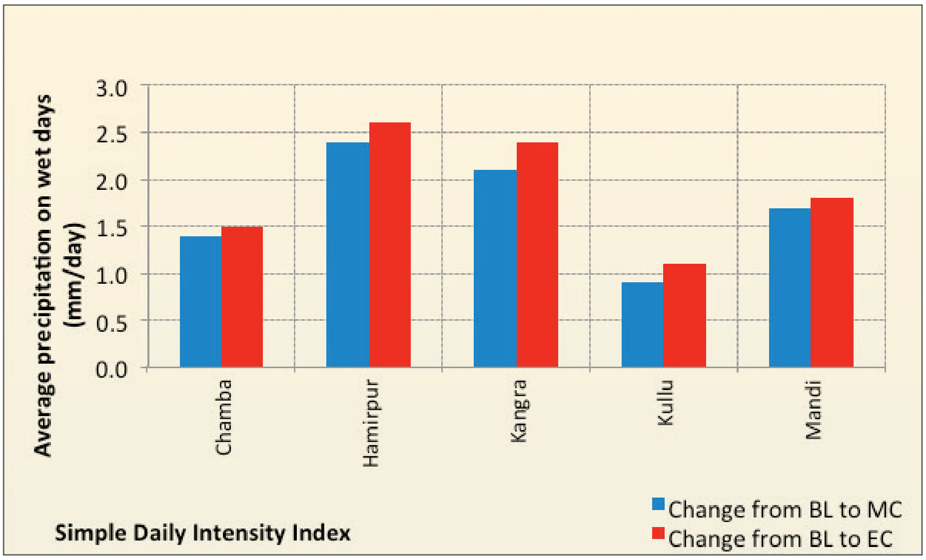


***Figure 36 (d)** Characteristic of projected changes in average precipitation on wet days for districts of Pong Dam lake basin (IPCC AR5 RCP 8.5 scenario)*

IMPACT OF CLIMATE CHANGE ON HYDROLOGY

Many hydrological processes, such as precipitation, evapotranspiration, and run-off, are significantly affected by climatic conditions. Such influences are further multiplied by climate change, which is now a scientific fact instead of a hypothesis. Moreover, these influences lead to a variety of complexities in forecasting and in analysing critical water-related parameters such as baseflow and flooding frequency (Chien et al., 2013). Climate change is one of the important factors causing combined effects on the hydrological cycles and associated water resource systems in specific watersheds. To achieve sustainable water resource management at the watershed scale, it is of importance to predict and analyse future tendencies in water resources through advanced tools over the long term. Therefore, the generation and analysis of the synergic effects of human activities and climate change on water balance and water resource systems are desired, which thus calls for effective modelling tools.

The impact of future climate changes on water balance in the Pong river basin and wetland has been analysed using the scenarios of RCP 4.5 and 8.5 of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The climate data indicates that both precipitation and temperature increased at seasonal and annual scales under RCP4.5 and 8.5. Impact of the same on the hydrological regime of the Pong Dam lake has been analysed in this section. Water balance of both RCP4.5 and RCP8.5 at mid- and end-century, is analysed for annual, monsoon (June, July, August and September) and post-monsoon seasons (October, November and December).

The climate change simulations for water resources are run using a bias-corrected multi-model ensemble of 10 high-resolution regional climate models and for IPCC AR5 RCP 4.5 and RCP 8.5 scenarios. The model has been run using climate scenarios for near (MC) and long-term (EC) periods (2021–2050 and 2071–2100, respectively) without changing the land use. Daily weather parameters (rainfall, temperature, solar radiation, relative humidity and wind speed) have been extracted for the relevant grids falling in the basins of various rivers. Before using climate model data in impact studies, bias correction has been applied to reduce the uncertainties in historical observed weather. The outputs of these scenarios have been analysed to evaluate the possible impacts on the run-off, baseflow, soil moisture, groundwater recharge and actual evapotranspiration (expressed as a change between the baseline and future periods).

CHANGE IN WATER BALANCE COMPONENTS (RCP4.5)

Average water balance components over 30 years, including baseline (1981–2010), mid-century (2021–2050) and end-century (2071–2100) scenarios, have been used for assessing change from baseline to mid- and end century. The effects of climate change on the water balance components have been analysed spatially with respect to the sub-basins of Pong Dam lake basin. The spatial distribution of water balance components has been plotted in terms of the percent change from the baseline period. Figure 37, Figure 38 and Figure 39 respectively show the spatial distribution of change from baseline for annual, monsoon and non-monsoon periods.

RCP4.5 Scenario: Annual

Mid-century: An increase in precipitation by 5% is projected on annual scale for Pong Dam lake basin towards mid-century and the same will lead to 6% increase in water yield. Most of the increase in precipitation is projected to contribute to stream flow and evapotranspiration. An increase in evapotranspiration is also observed in Mandi and Kullu districts. Run-off generation from snow will contribute to increase in the surface run-off. Surface run-off is lower in Mandi district on account of irrigation happening in the area, which is evident from higher evapotranspiration. The temperature increase in the future will contribute to more surface run-off. Groundwater recharge is also high in Kangra, Hamirpur and part of Mandi district (see Figure 37).

End-century: An increase in precipitation by 11% is projected on annual scale for Pong Dam lake basin towards end-century and the same will lead to 12% increase in water yield. Most of the increase in precipitation is projected to contribute to stream flow and evapotranspiration. An increase in evapotranspiration is also observed in Mandi and Kullu districts (see Figure 37).

IPCC AR5 RCP4.5 Scenario – Annual

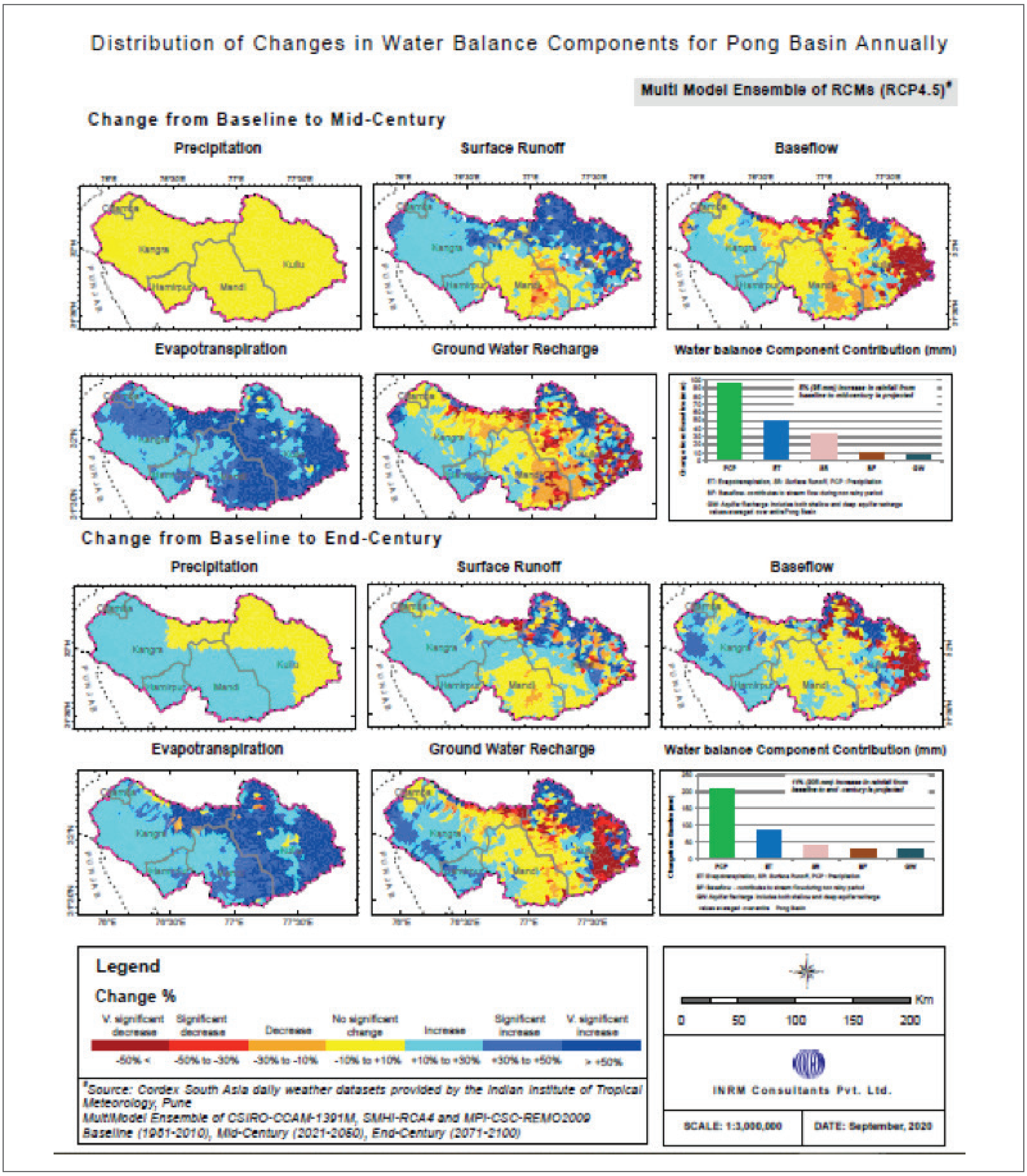


Figure 37 Spatial Distribution of Change in Water Balance for Pong Basin – Annual (IPCC AR5 RCP 4.5 Scenario)

RCP4.5 Scenario: South-West Monsoon (JJAS)

Mid-century: An increase in precipitation by 15% is projected in south-west monsoon (JJAS) for Pong Dam lake basin towards mid-century and the same will lead to 16% increase in water yield. Most of the increase in precipitation is projected to contribute to stream flow. An increase in evapotranspiration is also observed upstream of the basin. Kangra, Hamirpur, Chamba and part of Mandi district shows marginal reduction in evapotranspiration, which is a clear indication of change in rainfall intensity and low soil moisture retention. Kangra and Hamirpur districts show 10% to 50% increase in stream flow, while other districts show a very marginal change. Groundwater recharge is also high in Kangra, Hamirpur and part of Mandi district (see Figure 38).

End-century: An increase in precipitation by 22% is projected in south-west monsoon (JJAS) for Pong basin towards end-century, and the same will lead to 20% increase in water yield (see Figure 38). Most of the increase in precipitation is projected to contribute to stream flow. An increase in evapotranspiration is also observed upstream of the basin. The total groundwater recharge is projected to increase by 17%.

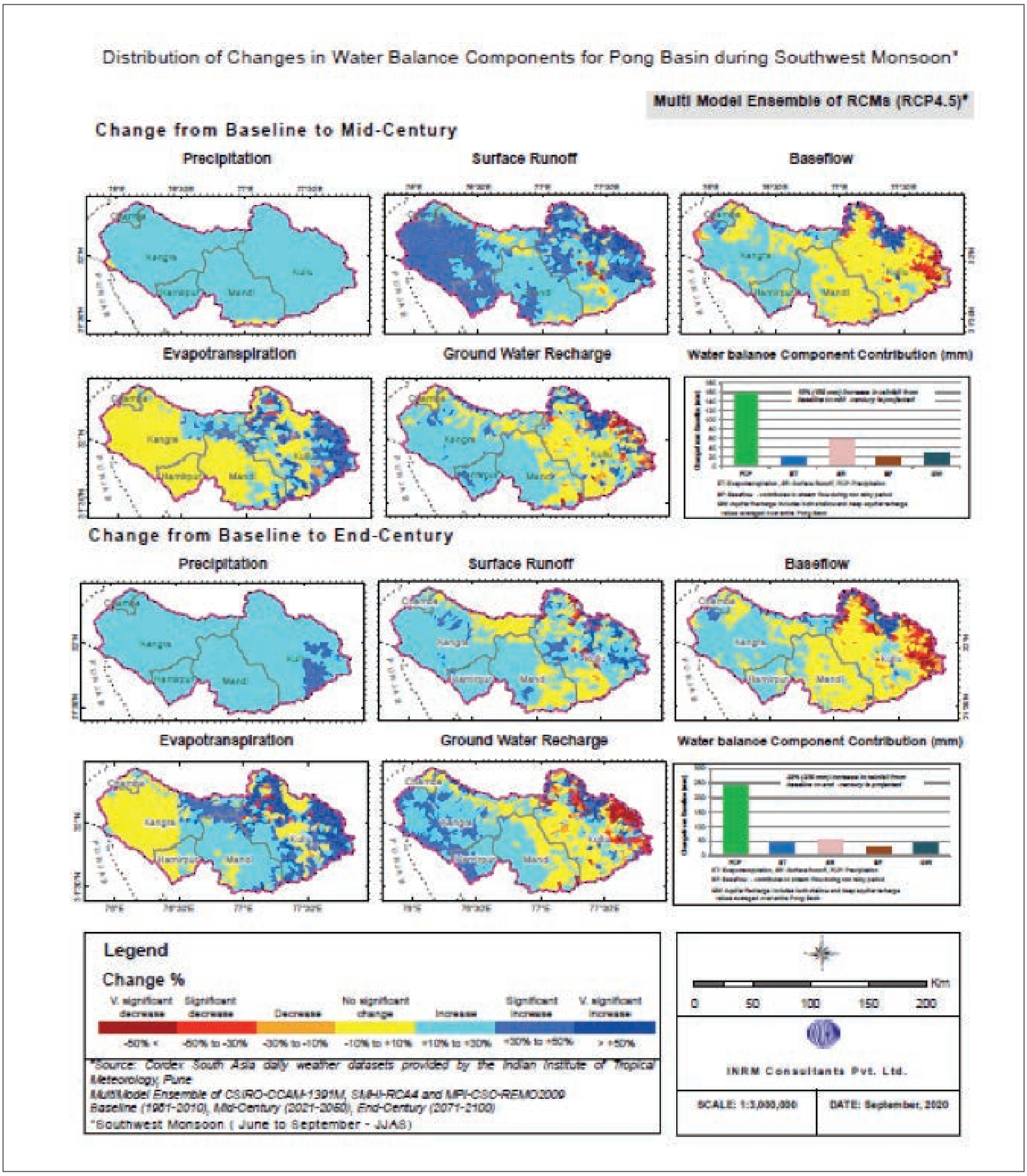


Figure 38 Spatial Distribution of Change in Water Balance for Pong Basin during Monsoon (IPCC AR5 RCP 4.5 Scenario)

RCP 4.5 Scenario: North-East Monsoon (OND)

Mid-century: A decrease in precipitation by 5% is projected in north-east monsoon (OND) towards mid-century. Marginal decrease in precipitation is projected for all the districts, while part of Kangra and Hamirpur districts show 10% to 30% reduction in precipitation. The reduction in winter precipitation would call for additional irrigation for the Rabi crops. The additional irrigation amount is likely to result in increase in baseflow and evapotranspiration. Marginal to 50% decrease in groundwater discharge is projected in the entire basin towards MC in north-east monsoon(see Figure 39).

End-century: An increase in precipitation by 18% is projected towards end-century, and the same will lead to 20% increase in water yield. There is a projected increase in evapotranspiration, and an increase in precipitation is projected to contribute to stream flow(see Figure 39).

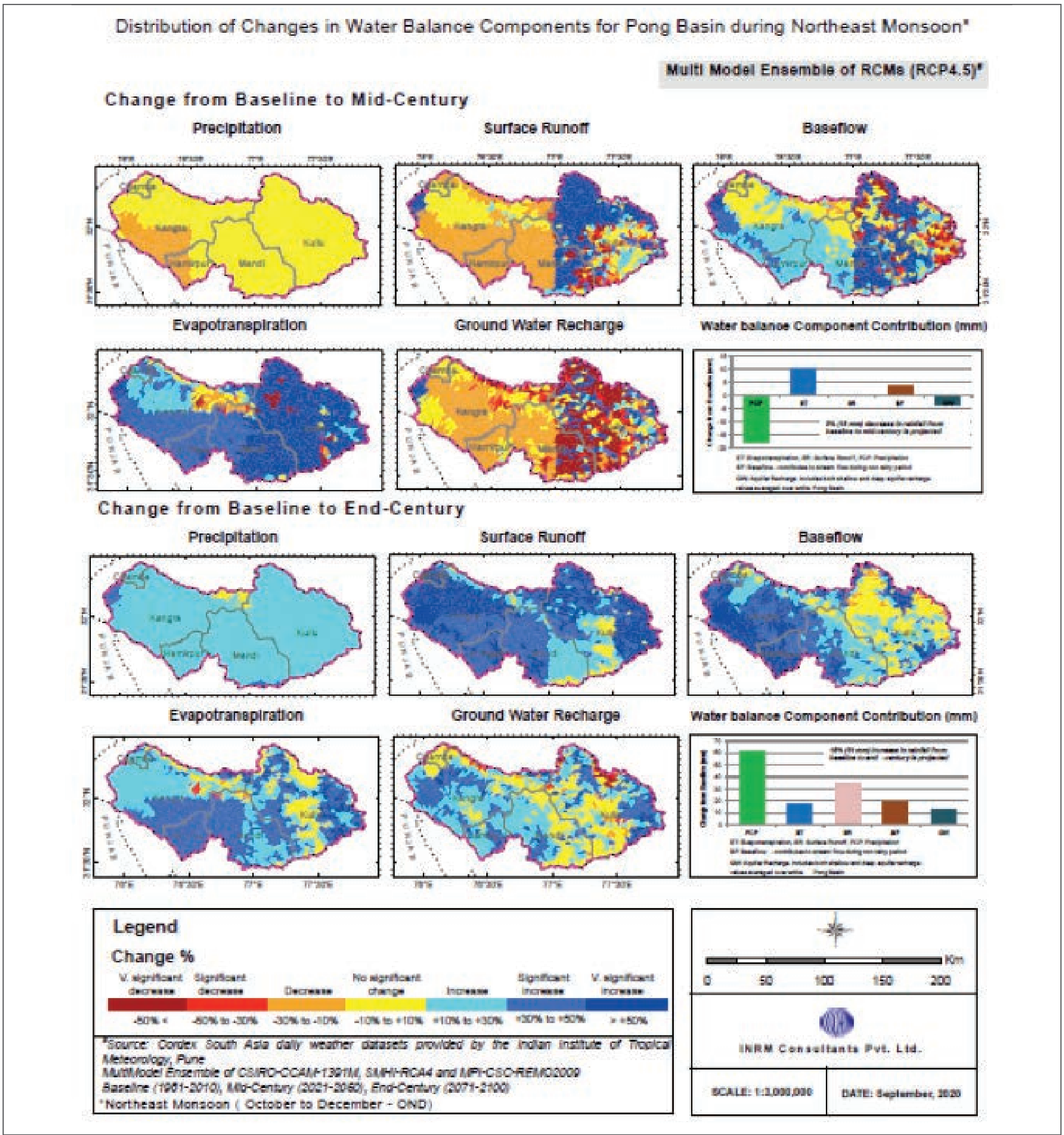


Figure 39: *Spatial Distribution of Change in Water Balance for Pong Basin during Non-Monsoon (IPCC AR5 RCP4.5 Scenario)*

CHANGE IN WATER BALANCE COMPONENTS (RCP 8.5)

Average water balance components over 30 years, including baseline (1981–2010), mid-century (2021–2050) and end-century (2071–2100) scenarios have been used for assessing change from baseline to mid- and end-century. The effects of climate change on the water balance components have been analysed spatially with respect to the sub-basins of Pong Dam lake basin. The spatial distribution of water balance components has been plotted in terms of the percent change from the baseline period. Figure 40, Figure 41 and Figure 42 respectively show the spatial distribution of change from baseline at annual, monsoon and non-monsoon periods.

RCP 8.5 Scenario: Annual

Mid-century: The RCP8.5 scenario indicates a projected increase in annual precipitation in Pong Dam lake basin of about 12% towards mid-century and the same shall lead to 20% increase in water yield together with snow melt. Most of the increase in precipitation is projected to contribute to stream flow and baseflow. A marginal reduction in evapotranspiration is projected, indicating a change in the distribution pattern of rainfall. Similarly, increase in precipitation is likely to return as groundwater recharge. Stream flow and groundwater recharge is projected to increase in all the districts towards the mid-century for RCP 8.5 scenario. Reduction in evapotranspiration suggests that water availability for crop growth will reduce, impacting the evapotranspiration of the basin (see Figure 40).

End-century: The projected increase in annual precipitation in Pong Dam lake basin is about 10% by end-century, whereas Kullu and Mandi districts do not show any significant change. The model results indicate that most of the increase in precipitation will get translated to an increase in stream flow. The total aquifer recharge is projected to increase and evapotranspiration will decrease. An increase in precipitation, stream flow and groundwater recharge is projected for all the districts (marginal to 50%) towards the end-century for RCP 8.5 scenario. All the districts are likely to have a reduction in evapotranspiration. Evapotranspiration directly accounts for the amount of water getting evaporated and utilized by the crop. Reduction in evapotranspiration suggests that the plant requirement is not getting fulfilled by the available water and also that increase in temperature is not allowing the plant to grow. It calls for a major change in cropping pattern and timing of sowing and harvest in the basin to sustain the agricultural practices in the area.

Mandi district shall be impacted the most wherein the scenario is worse than the mid-century. It suggests that increase in rainfall will not help in providing adequate water to the crop. It is also evident from the climate data analysis above that rainfall intensity has increased whereas overall distribution of the rainfall has reduced, causing more flood-like events. Alteration in temperature will impact the growth cycle of the plants. This shift and increase in temperature and warm spell calls for a major shift in the agricultural practices of the area (see Figure 40).

IPCC AR5 RCP8.5 Scenario – Annual

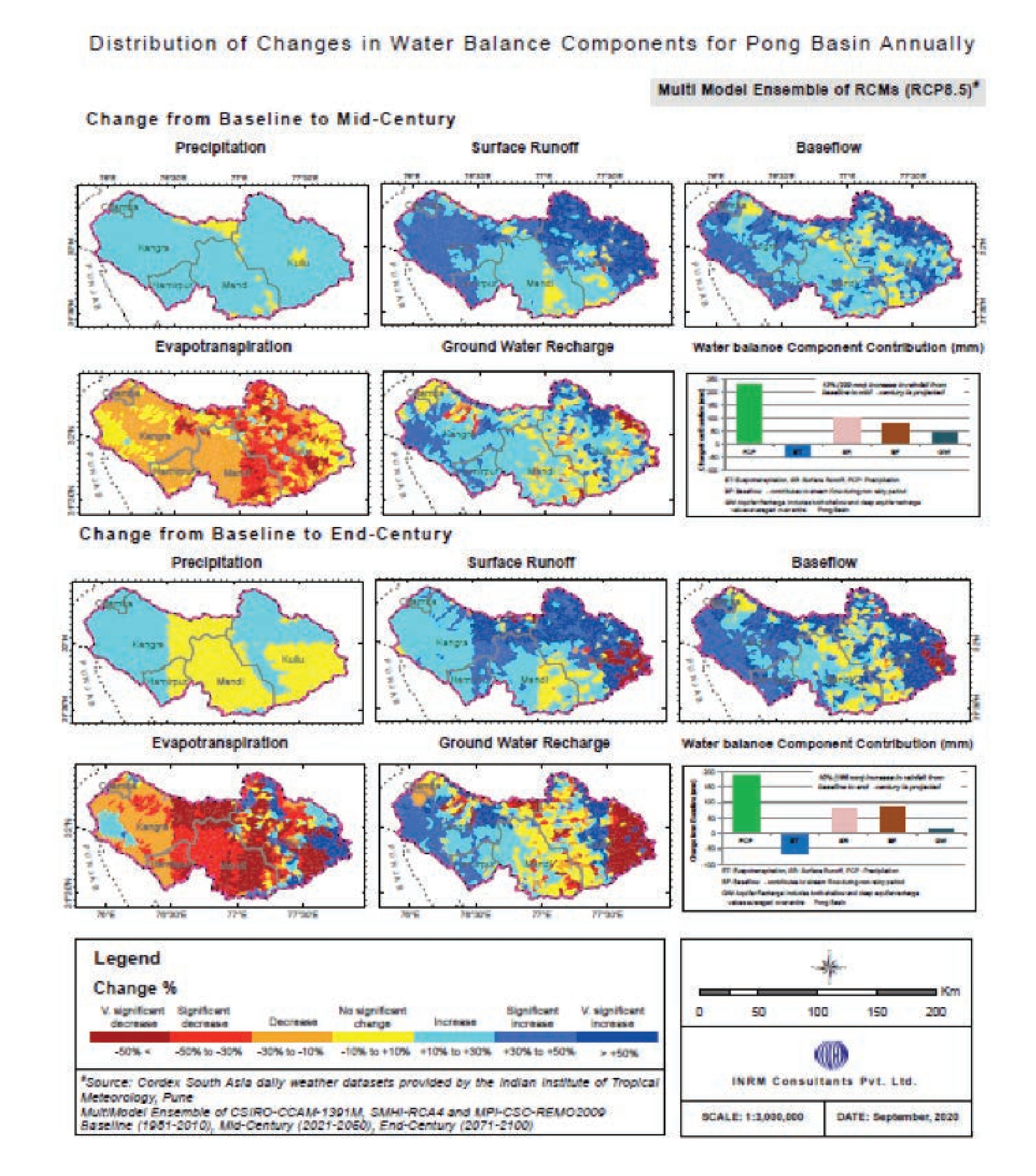


Figure 40 *Spatial Distribution of Change in Water Balance for Pong Basin – Annual (IPCC AR5 RCP 8.5 Scenario)*

RCP 8.5 Scenario: South-West Monsoon (JJAS)

Mid-century: The RCP8.5 scenario indicates a projected increase in south-west monsoon (JJAS) precipitation in Pong basin of about 18% towards mid-century and the same shall lead to 25% increase in water yield together with snow melt. Most of the increase in precipitation is projected to contribute to stream flow. A marginal reduction in evapotranspiration is projected, indicating a change in the distribution pattern of rainfall. Similarly, increase in precipitation is likely to return as groundwater recharge. Stream flow and groundwater recharge is projected to increase in all the districts towards the mid-century for RCP8.5 scenario (see Figure 41).

End-century: The projected increase in south-west monsoon (JJAS) precipitation in Pong Dam lake basin is about 25% towards end-century and the same will lead to 34% increase in water yield together with snow melt. The model results indicate that most of the increase in precipitation will get translated to an increase in stream flow, baseflow and groundwater recharge. The total aquifer recharge is projected to increase and there is decrease in evapotranspiration. An increase in precipitation, stream flow and groundwater recharge is projected for all the districts (marginal to 50%) towards the end-century for RCP 8.5 scenario. All the districts are likely to have a reduction in evapotranspiration. Decrease in evapotranspiration suggests that although rainfall has increased, overall distribution of the rainfall in the basin has altered. The available water is not enough to fulfil the plant requirement and also increase in temperature does not allow the plant to grow. It calls for a major change in cropping pattern and timing of sowing and harvest in the basin to sustain the agricultural practices in the area. Increase in surface run-off suggests that there will be more high-intensity rainfall events causing flood-like situation in the catchment, but overall distribution of rainfall will reduce, causing decrease in evapotranspiration (see Figure 41).

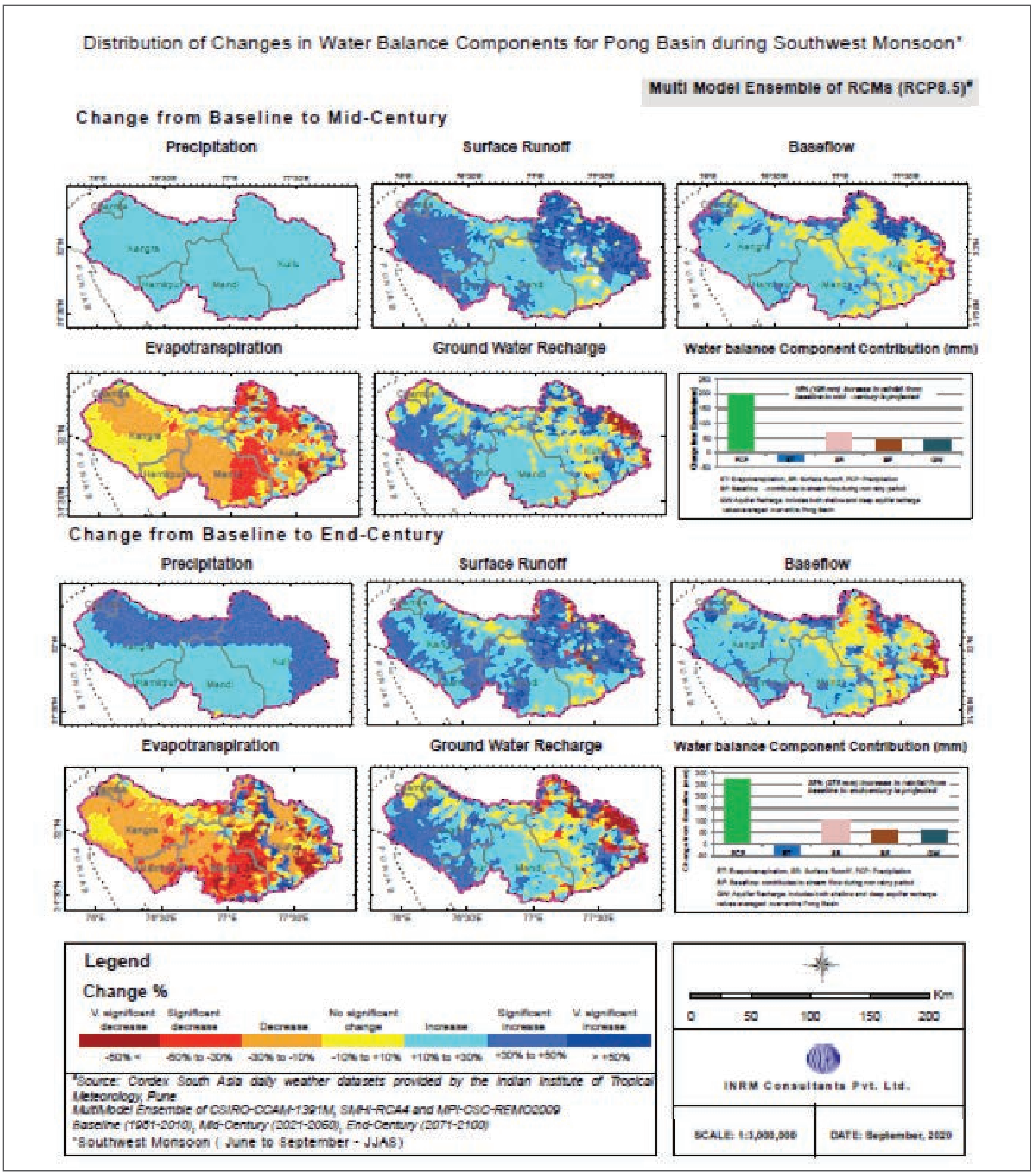


Figure 41 *Spatial Distribution of Change in Water Balance for Pong Basin during Monsoon (IPCC AR5 RCP 8.5 Scenario)*

RCP 8.5 Scenario: North-East Monsoon (OND)

Mid-century: An increase in precipitation in north-east monsoon (OND) of about 26% is projected towards mid-century and the same shall lead to 40% increase in water yield together with snow melt. A marginal reduction in evapotranspiration and an increase in stream flow are observed in the study area. Most of this increase in precipitation is likely to return as direct surface run-off and baseflow. All the districts are likely to have an increase in stream flow due to high-intensity rainfall. All districts show reduction in evapotranspiration due to change in temperature and non-availability of soil moisture. A major change is required in cropping pattern and timing of sowing and harvest in the basin to sustain the agricultural practices in the area (see Figure 42).

End-century: The projected increase in north-east monsoon (OND) precipitation in Pong Dam lake basin is about 12% (40 mm) by end-century and the same shall lead to 45% increase in water yield together with snow melt. Significant reduction in evapotranspiration is observed in all the districts. The model results indicate that most of this increase in precipitation will get translated to an increase in stream flow, baseflow and groundwater recharge. The total aquifer recharge is projected to increase and evapotranspiration will decrease. An increase in precipitation, stream flow and groundwater recharge is projected for all the districts (marginal to 50%) towards the end-century for RCP 8.5 scenario. The evapotranspiration situation is alarming. This could be because of the temperature which might not be suitable for crop growth. Hence, results suggest that a major change in cropping pattern and sowing and harvest timing is needed. There is significant increase in the surface run-off and baseflow, suggesting more flood-like situations in the basin. Also there is enhancement in groundwater recharge (see Figure 42).

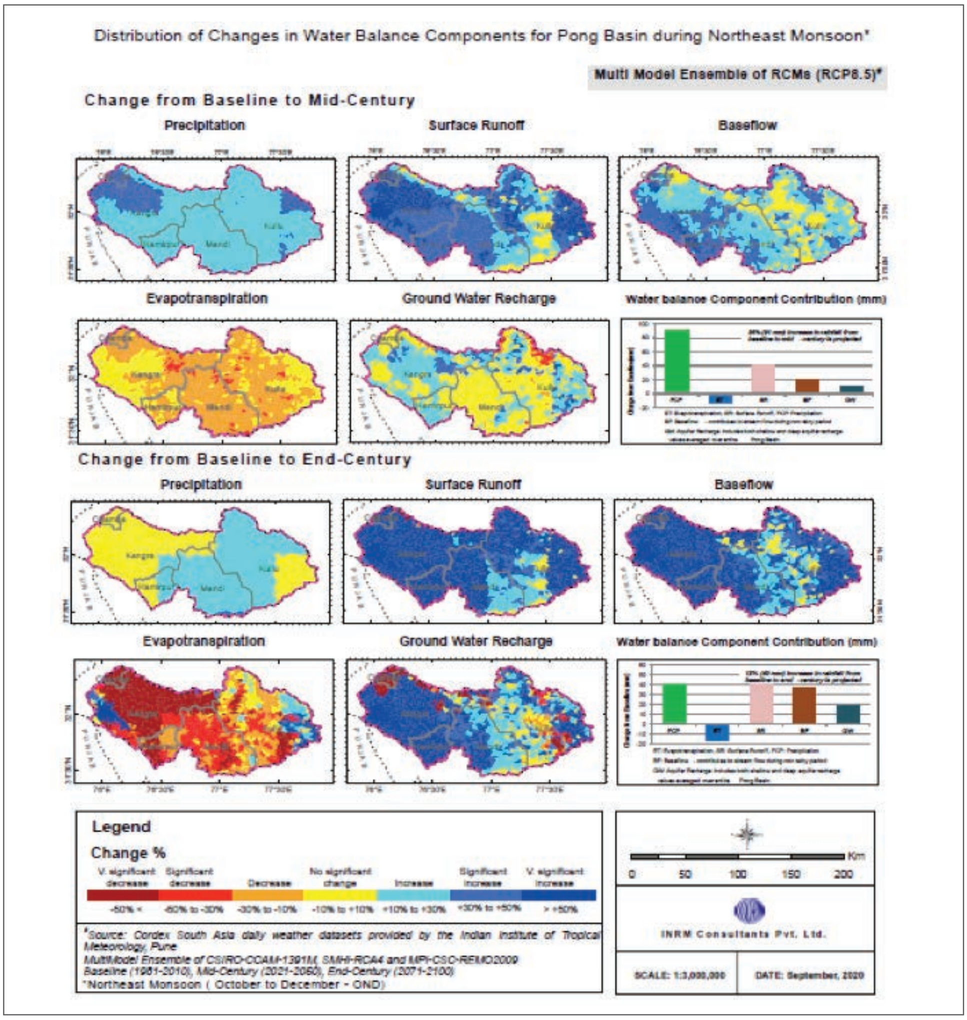


***Figure 42** Spatial Distribution of Change in Water Balance for Pong Basin during Non-Monsoon (IPCC AR5 RCP 8.5 Scenario)*

SEDIMENT STUDY

Sediment in a stream is natural, but if sediment levels get too high, it can disrupt ecosystems. Excess sediments can cause damage by blocking light that allows algae (an important food source) to grow, harming fish gills, harming important habitats and reducing visibility for the fish to move around or feed. Sedimentation can affect hydropower production due to loss of reservoir storage and damage mechanical components of the hydropower. Sediments deposited in reservoirs may affect the safety of dams and negatively impact the environment. Reduced capacity of the reservoir increases the flood risk. Sedimentation is influenced by the geology of the surrounding area. In the current study, sediment data has been collected from the Compendium on Siltation of Reservoirs, H.P. (2015) and remotely sensed data from Landsat-4 MSS, Landsat-5 TM, Landsat-8 OLI/TIRS and Sentinel acquired from USGS Earth Explorer for analysis and study. Sedimentation rates in Pong Dam lake using different methods, as well as area prone to sedimentation have been analysed in this study.

Accelerated soil and water loss which are caused by human activities and natural factors, seriously threaten land resources, water resources and ecological environment. Soil erosion is posing a severe challenge to the productivity of land throughout the world. This alarming situation requires urgent interventions in order to preserve water and soil resources. Sediment transport and deposition are non-linearly related and influence factors spatially and temporally. Soil erosion and lake sediment loading are severe ecological and environmental problems faced by watershed managers around the world.

Soil erosion is a serious problem in India. Soil erosion and sediment transport in a river basin are largely governed by topographical, meteorological, land cover, soil and drainage characteristics in the basin (Durbude & Purandara, 2005). The procedure of watershed erosion, sediment transport and its subsequent deposition in reservoirs is a widespread occurrence. Sediment is originated in the form of erosion due to natural as well as anthropogenic activities in the catchment and propagates along with the river flow.

All water storage structures constructed on natural rivers are subjected to reservoir sedimentation. The reservoir sedimentation is filling of the reservoir behind a dam with sediment carried into the reservoir by streams. The sediment particles which originate from erosion processes in the catchment are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediment settles down in the reservoir and reduces its capacity. Decrease in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was constructed. Therefore, assessment of sediment deposition becomes very important for the management and operation of such reservoirs.
In the present study the sediment deposition in a reservoir is estimated through the following means:

- Using remote sensing databased digital image processing technique: To assess the sedimentation in Pong Dam lake, Landsat satellite data from maximum to minimum reservoir level were used to evaluate temporal and spatial patterns of reservoirs. The water-spread areas of the reservoirs were assessed by using a band rationing technique, i.e. Normalized Difference Water Index (NDWI). Furthermore, the revised capacities of the reservoirs between minimum and maximum levels were computed using the trapezoidal formula.
- Using the SWAT (Soil and Water Assessment Tool) hydrological model, which has the capability to calculate the sediment loading at a reservoir.

In the following sections, each of the processes and their results are discussed in detail. Inter-model comparison and comparison with observed data have been carried out to validate the results.

USING REMOTE SENSING IMAGES

For the present study, Landsat satellite data which has a resolution of 30 m was used. This multi-spectral data has information of four bands, which is very helpful for identifying the water-spread area of reservoirs. In this study, digital image processing was carried out for identifying the water pixels and for determining the water-spread area. Apart from remote sensing data, hydrographic survey data of reservoir water elevation and actual reservoir area were obtained from the BBMB. However, to assess the temporal and spatial patterns of the water-spread area of the reservoirs, remote sensing data of Landsat satellite were used (Shukla et al., 2017). Two years' data were analysed to estimate the sedimentation rate. The sedimentation rate of 2008–2009 was validated with the published work.

STEPS INVOLVED

Selection of period for analysis

Selection of the appropriate period for analysis is an important step in the study of reservoir sedimentation assessment using remote sensing data. The months may slightly vary in case multi-year analysis is performed. Variation in month is on the account of clear, cloud-free image availability. The only useful information extracted from the remote sensing data is the water-spread area at different dates when the satellite passes over the reservoir area. Although in the 0.45 to 0.52μm wavelength region, the information within 1 to 2m depth below the water surface (like sediment concentration, shallow water depth) can be obtained, it cannot be used to quantify the amount of sediment deposited in the reservoir. Therefore, it is imperative to use remote sensing data of such a period when there is maximum variation in the elevation of the reservoir water level and the water-spread area.

In the study area, the reservoirs generally attain the highest level near the end of the monsoon period (October–November) and then deplete gradually before the onset of the next monsoon (June–July). Therefore, temporal remote sensing data for any water year (October–July) can be selected for analysis. A wet year, followed by a dry year is the best period for such type of sediment deposition study. The reservoir water level is likely to fluctuate from the maximum to the minimum level which is generally attained during the operation of the reservoir. Besides technical reasons, there might be some administrative reasons to select the period of analysis. In the present study, historical records of annual maximum and minimum reservoir levels were obtained from the BBMB. For the current study, 2008–2009 and 2015–2016 data were used.

Processing of remote sensing images

The analysis involves pre-processing of satellite data, i.e. geometric and radiometric correction. The identification of the water pixels in terms of water-spread area by using a band rationing technique has been performed with the help of ERDAS IMAGIN9.3 and ArcGIS software. The pixels representing water-spread area of the reservoir were clearly distinguishable in the False Colour Composite (FCC) image. The demarcation of the reservoir was identified by using a band rationing technique, i.e. Normalized Difference Water Index (NDWI). The NDWI is used for water body mapping, as water bodies strongly absorb light in the visible to infrared electromagnetic spectrum. NDWI uses green and near-infrared bands to highlight water bodies. The NDWI value ranges from −1 to 1 considering zero value as a threshold. Based on the NDWI value, the satellite images are classified as water or non-water. For values of NDWI>0, the cover type is water and if NDWI ≤ 0, the cover type is non-water. The digital number (DN) value of water pixels is always in the near-infrared (NIR) spectral region. If the generated DN value is lower than the DN value of Band 2 and Band 3, then it is classified as water, otherwise it is treated as non-water. Initially, the FCC of satellite data were generated and visualized.

The water-spread area was estimated using the Normalized Difference Water Index (NDWI) band rationing technique.
The index is calculated using following formula:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where,

Green is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to

- Maximize the typical reflectance of water features by using green light wavelengths
- Minimize the low reflectance of NIR by water features
- To take advantage of the high reflectance of NIR by terrestrial vegetation and soil features

Processed remote sensing images depicting water-spread in different seasons and dates are shown in Figure 43 and Figure 44 for 2008–2009 and 2015–2016 respectively.

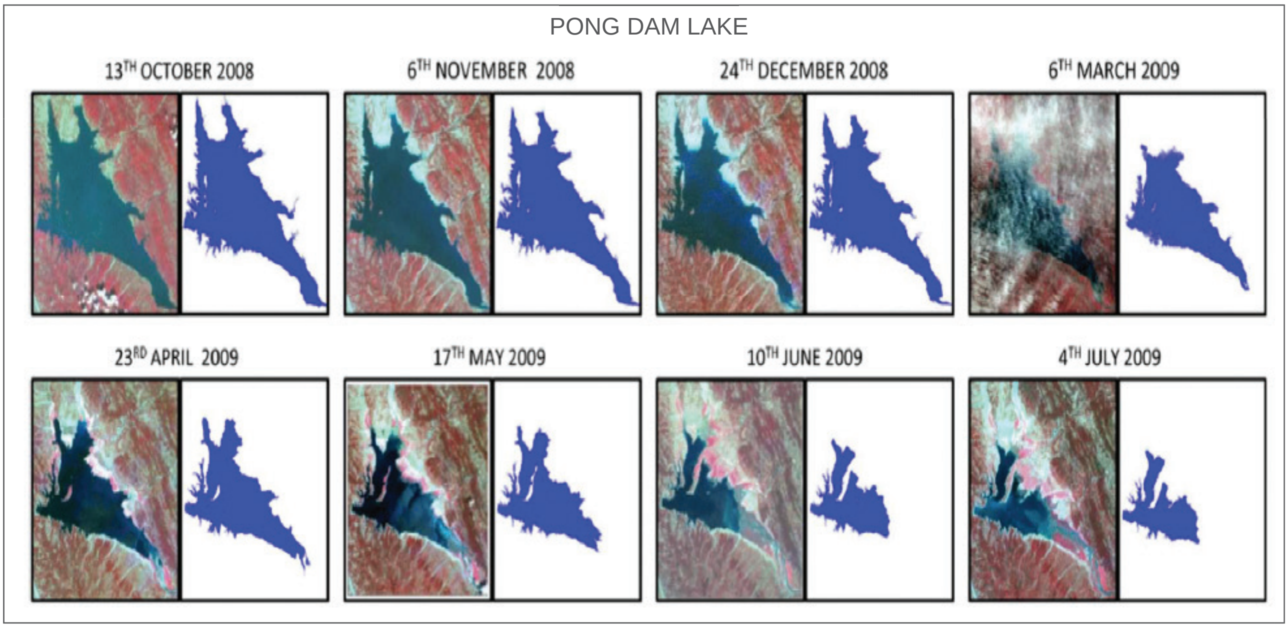


***Figure 43** Water-spread of Pong Dam lake during Different Months in Year 2008–2009*

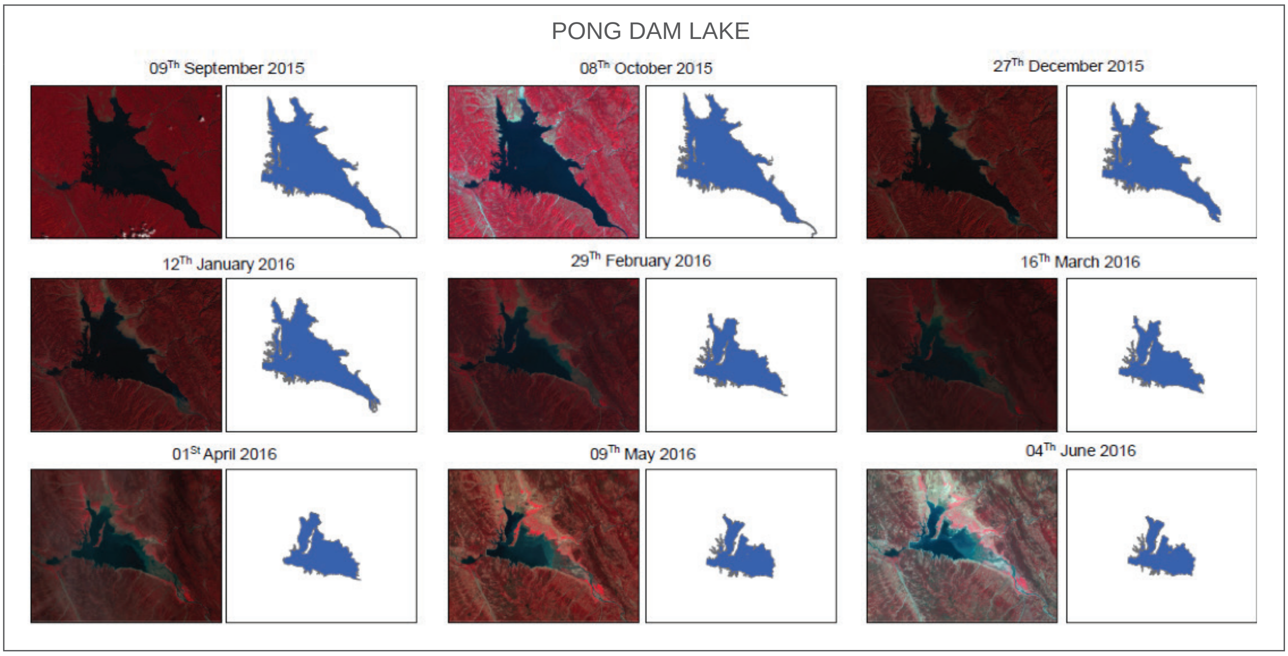


***Figure 44** Water-spread of Pong Dam lakeduring Different Months in Year 2015–2016*

Calculation of the volume of sediments

The capacity of the reservoir between two consecutive elevations was computed using the trapezoidal formula.

$$V = \frac{h}{3} A_1 + A_2 + \sqrt{(A_1 + A_2)}$$

where,

V = Volume between two consecutive levels

h = Difference between consecutive elevations

A1 = Contour area at elevation 1

A2 = Contour area at elevation 2

Calculations and Results

In the present study, the area, volume and cumulative revised capacities of the reservoirs were calculated by using remote sensing techniques. To estimate the capacities of reservoirs for the years 2008–2009 and 2015–2016, different elevations were selected based on live storage, elevation interval and the availability of cloud-free data.

Further, the Area–Elevation–Capacity curve of Pong Dam lake was used, which was obtained from literature (Shukla et al., 2017).1F The calculations of sediment volume are given in Table 3 and Table 4. The hydrographic survey data published by BBMB for Pong Dam lake were used for the study. From the Area-Elevation-Capacity curve, the original areas at the intermediate elevations (reservoir elevations on the dates of satellite pass), were obtained by linear interpolation. To compute the water-spread area at a closer interval, a curve (best-fit line) between elevation and water-spread area was drawn. From these curves, the area corresponding to the closer interval was calculated. The water-spread areas of the reservoirs were calculated using satellite data and applying the Normalized Difference Water Index (NDWI) approach. In order to calculate loss in storage and to know sedimentation rate, the original capacity and capacity computed in years 2008–2009 and 2015–2016 respectively, were compared. The difference between the cumulative capacities of original (base year) and analysis years (2008–2009 and 2015–2016) gave the loss in storage in live storage zone (Figure 46). While calculating the capacities of the reservoir, the volume at the lowest level has been taken as zero. The difference between the original and estimated cumulative capacity represents the loss of capacity due to sedimentation. A flow chart of the complete sedimentation process is shown in Figure 45. Area–Capacity table of Pong reservoir is given in Table 2.

Photo credit: CarrotFilms.GIZ

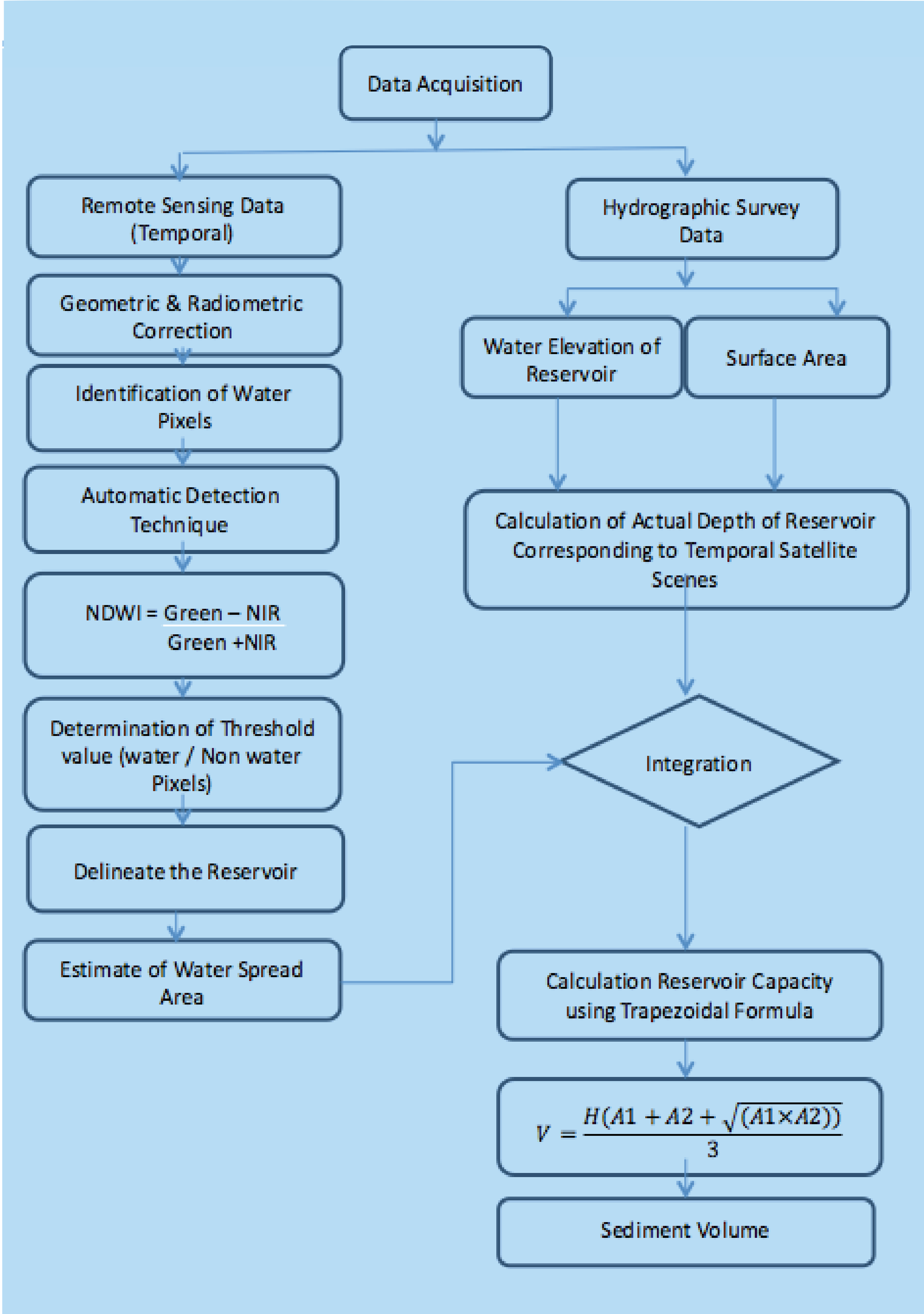
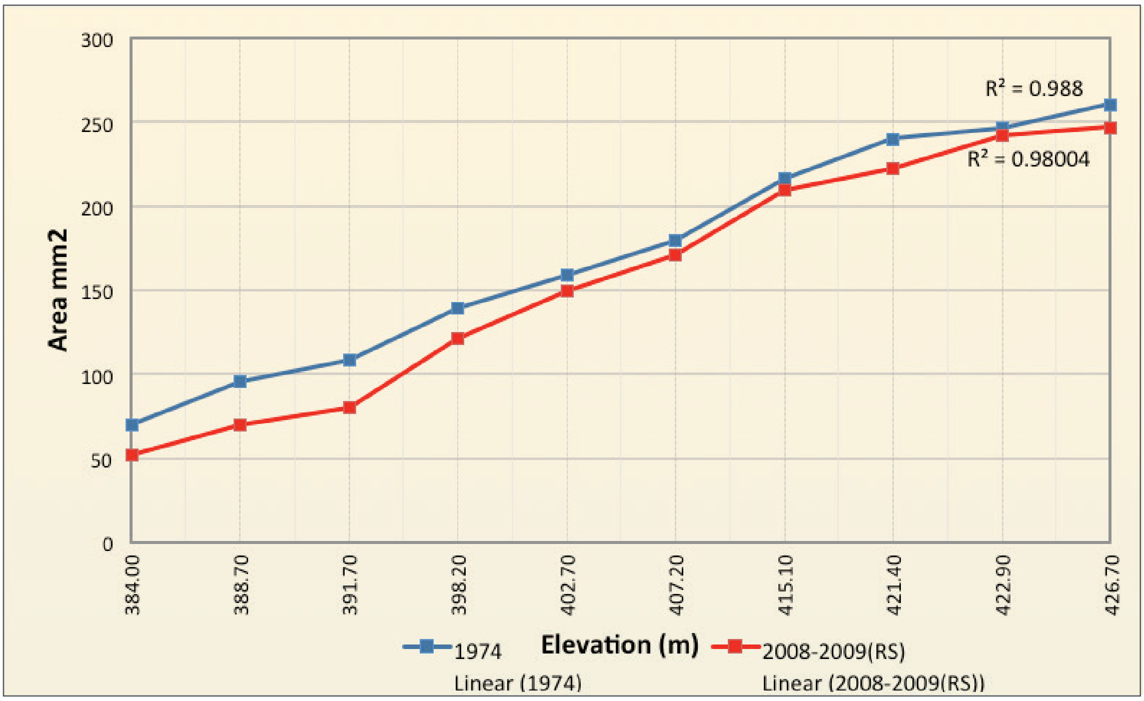


Figure 45 *Flow Chart of the Complete Sedimentation Study Process*



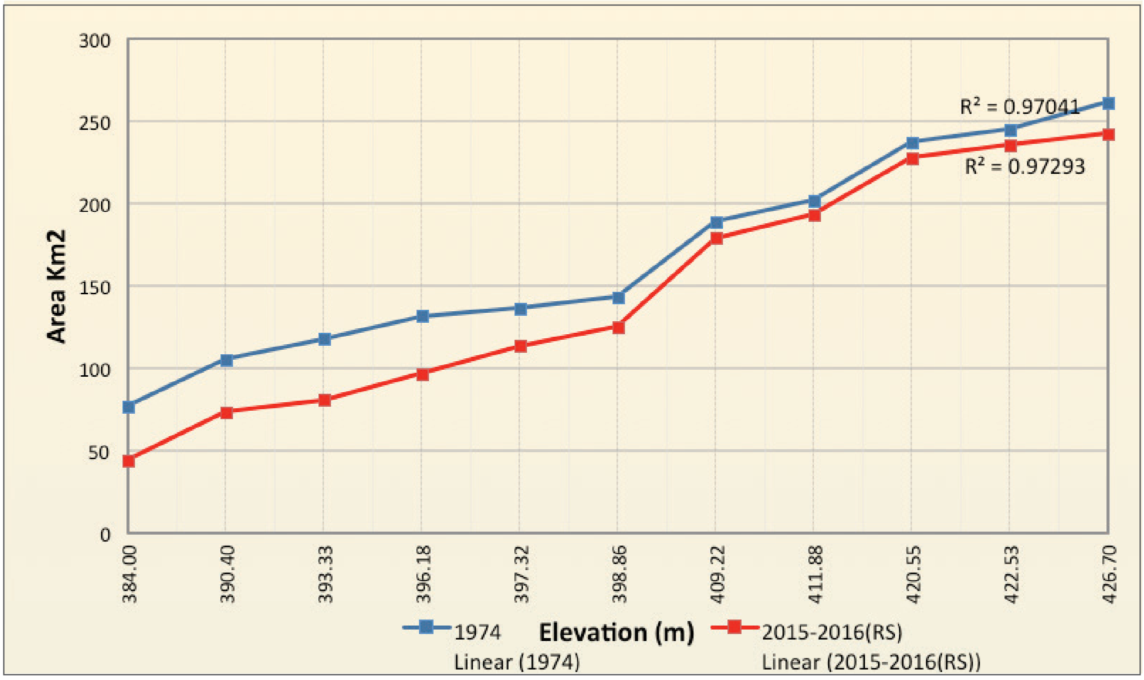


Figure 46 *Capacity Loss Due to Sedimentation in Pong Dam lake in Year 2008–2009 and 2015–2016*

Table 2 Area–Capacity Table of Pong Reservoir

Pong Reservoir Area–Capacity Table		
Reservoir Elevation (m)	Area (km^2)	Capacity (Mm^3)
426.72	260.64	8582.05
425.00	254.60	8129.00
420.00	234.79	6906.00
415.00	215.81	5779.00
410.00	192.86	4757.00
405.00	169.17	3852.00
400.00	147.59	3060.00
395.00	125.35	2378.00
390.00	100.83	1813.00
385.00	80.80	1359.00
380.00	64.13	996.00
375.00	51.56	708.00
370.00	40.57	478.00
365.00	31.55	299.00
360.00	21.70	164.00
355.00	13.41	79.00
350.00	7.12	26.00
345.00	2.00	6.00
340.00	0.38	0.60
335.00	0.00	0.00

The results of sedimentation for both the periods in the reservoir are shown in Table 3 and Table 4. The cumulative volumes shown in Table 3 and Table 4 are slightly different from the area–capacity curve, because level has been obtained from Minimum Drawdown Level and sediment calculation has been done only for the live zone because dead zone sedimentation will remain the same.

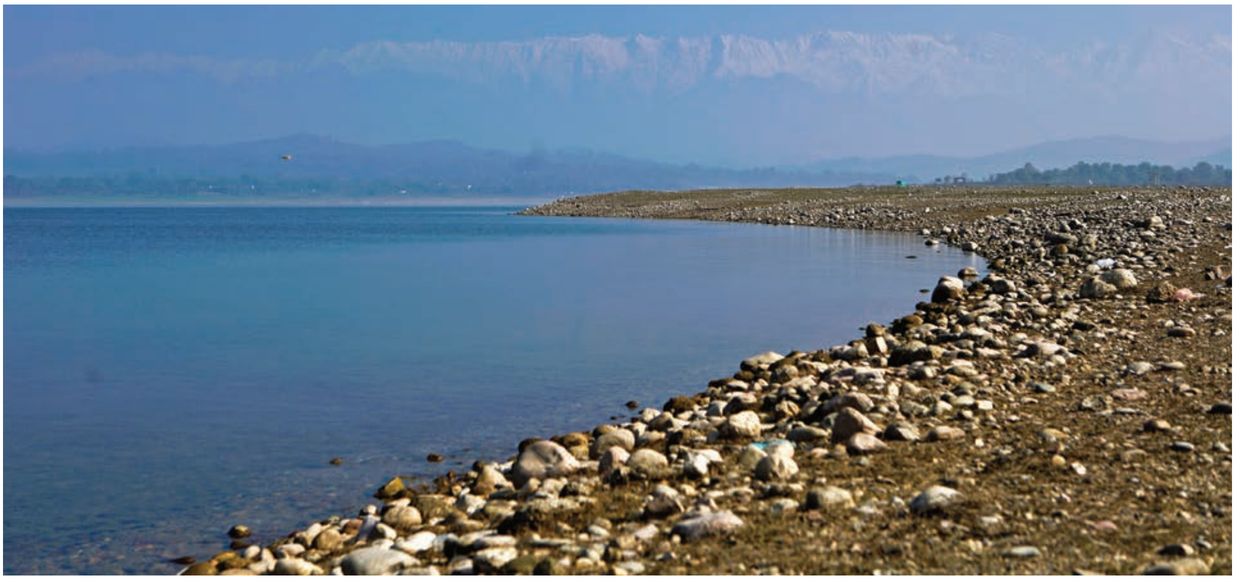


Photo credit: CarrotFilms.GIZ

Table 3 Calculation of Sediment Deposition in Pong Reservoir Using Remote Sensing for the Year 2008–2009

Year 2008–2009							
Date of Satellite Pass	Reservoir Elevation (m)	Original Area (km²)	Estimated Area (RS) (km²)	Original Volume (Mm³)	Estimated Volume (Mm³)	Original Cumulative Volume (Mm³)	Estimated Cumulative Volume (RS) (Mm³)
	426.7		247.00	963.17	930.42	7259.85	6639.27
13/10/2008	422.9	246.40	242.70	364.86	349.02	6296.68	5708.85
06/11/2008	421.4	240.10	222.80	1437.33	1361.85	5931.82	5359.83
24/12/2008	415.1	216.40	209.60	1561.54	1501.6	4494.49	3997.98
06/03/2009	407.2	179.50	171.20	762.08	722.4	2932.95	2496.38
23/04/2009	402.7	159.40	150.10	671.8	610.67	2170.87	1773.98
17/05/2009	398.2	139.40	121.80	804.94	651.81	1499.07	1163.31
10/06/2009	391.7	108.90	80.20	306.53	225.28	694.13	511.5
04/07/2009	388.7	95.60	70.10	387.6	286.22	387.6	286.22

Table 4 Calculation of Sediment Deposition in Pong Reservoir Using Remote Sensing for the Year 2015–2016

Year 2015–2016							
Date of Satellite Pass	Reservoir Elevation (m)	Original Area (km²)	Estimated Area (RS) (km²)	Original Volume (Mm³)	Estimated Volume (Mm³)	Original Cumulative Volume (Mm³)	Estimated Cumulative Volume (RS) (Mm³)
	426.70					7287.45	6491.18
06/09/2015	422.53	244.81	235.14	476.94	458.03	6233.76	5496.38
08/10/2015	420.55	236.97	227.54	1898.96	1821.08	5756.82	5038.35
27/12/2015	411.88	201.56	193.02	519.14	494.74	3857.86	3217.27
12/01/2016	409.22	188.84	179.05	1713.49	1567.89	3338.72	2722.53
29/02/2016	398.86	143.01	125.23	215.06	183.84	1625.23	1154.64
16/03/2016	397.32	136.31	113.62	152.56	119.68	1410.17	970.80
01/04/2016	396.18	131.35	96.57	354.63	252.40	1257.61	851.12
09/05/2016	393.33	117.64	80.79	325.57	225.97	902.98	598.72

From Table 3 and Table 4, the volume of sediment deposited can be estimated for both 2008–2009 and 2015–2016. The sedimentation rate worked out for 2008–2009 is 24.62 Mm³/year, and for 2015–2016 it is estimated as 25.79 Mm³/year.

SEDIMENT MODELLING USING THE SWAT MODEL

This section aims at evaluating the SWAT model for sediment yield simulation in Pong reservoir. Soil and Water Assessment Tool (SWAT) has been used for sediment simulation. SWAT is a very efficient distributed model, developed to predict run-off, erosion, sediment and nutrient transport from watersheds.

Sedimentation is a common phenomenon in all reservoirs. This study presents an application of the SWAT model to simulate water flow and sediment load from 1975 to 2018 in the Pong reservoir. Soil and Water Assessment Tool (SWAT) is a physically based model and commonly used in practice to simulate water and sediment fluxes in basins. The extensive application of the SWAT model confirms that its distributed hydrological model can be applied to a number of environmental processes at different time and spatial scales and SWAT model provides a powerful model for run-off simulation and sediment simulations. The SWAT model has been used to study the run-off and sediment in different sub-basins.

The SWAT hydrological model divides the water-shed into a number of meshes or representative basic units as calculation units, which reflects the differences in the factors affecting soil erosion in the sub-basin by assigning parameter values to the calculation units so as to achieve a more accurate prediction of run-off and sediment production in the entire basin.

The SWAT model was originally developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large ungauged basins. The SWAT model has a long-time modelling experience since it incorporates features of several models. Erosion and sediment yield are estimated for each hydrological response unit (HRU).Based on the available historical data of annual sedimentation rate at Pong reservoir from 1980 to 2011, the SWAT model was calibrated and validated at annual scale between 1980 and 2011.The SWAT model uses the modified universal soil loss equation (MUSLE) to calculate the sediment erosion. Sediment erosion is affected by the soil erosion factors, vegetation cover and operating management factors. The vegetation cover and operating management factors are closely related to the surface vegetation fraction and leaf crown coverage, so the latter parameters become the main adjustment parameters.

COMPARISON OF RESULTS (DIFFERENT TECHNIQUES)

The time series comparison of all methods of sedimentation calculations of the last 20 years is shown in Figure 47.

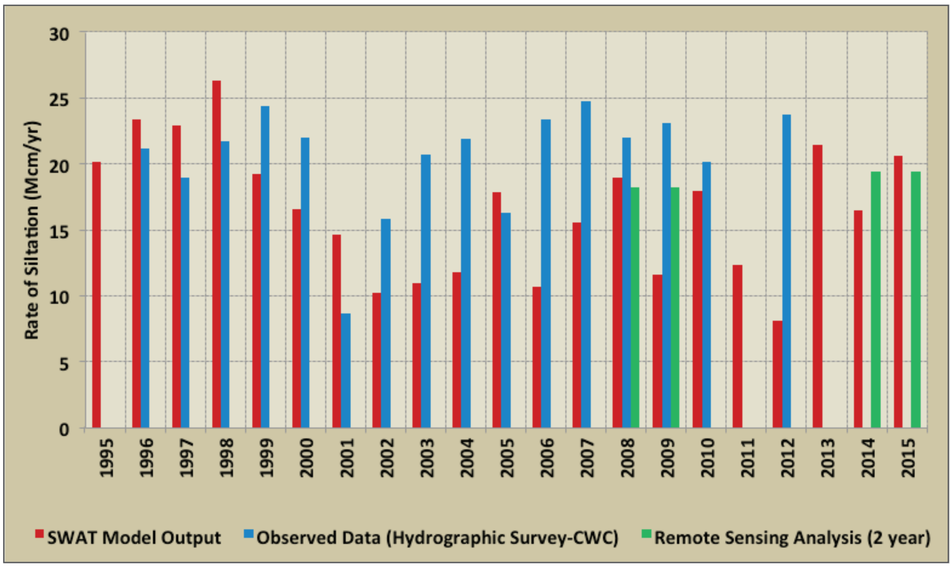


Figure 47 *Time Series Comparison of Sedimentation Rate using Different Techniques*
Source: INRM

As per the report prepared by BBMB, sedimentation rate estimated through the hydrographic survey[2] is 18.17 Mm^3/year in the live zone of the Pong Dam lake. However, simulated sedimentation rate through SWAT modelling[3] worked out to be 16.61 Mm^3/year and the rate obtained through remote sensing is 19.42 Mm^3/year (2015–2016). The simulated sedimentation rate till 2012 in Pong Dam lake was considered so that comparison with the observed data could be done. For remote sensing analysis, year 2008–2009 and 2015–2016 was considered because of two reasons:

- Maximum number of continuous clear images (cloud free) were available for these years.
- Year 2008–2009 was selected because it was a flood year and 2015–2016 was selected representing the dry year where shrinkage was maximum in the Pong Dam lake.

The comparison shown in Table 5 shows good match between all the methods and sources and thus, it can be confidently said that SWAT modelling output and remote sensing analysis can be used for finding the sedimentation rate.

There is a slight variation in SWAT simulated sedimentation rate and actual hydrographic survey data. This variation is on account of non-availability of the calibration data at the upstream location and also on account of changes on ground, which could not be captured as part of data gap. But the overall match fits well with the observed data for the two methods used for calculation of the sedimentation rate.

Table 5 *Comparison of Annual Sedimentation Rate (Mm^3/year) Using Different Methods and Sources*

S.No.	Method/Source	Sedimentation Rate (Mm^3/year) – Live Zone of Pong Reservoir	Sedimentation Rate (Mm^3/year) – Dead Zone of Pong Reservoir	Total Sedimentation Rate (Mm^3/year)
1	Hydrographic Survey – BBMB Report	18.17	6.37	24.54
2	Hydrographic Survey – CWC Report	18.03	6.37	24.40
3	Remote Sensing Analysis	19.42	6.37	25.79
4	SWAT Simulation	16.77	6.37	23.14

IMPACT OF CLIMATE CHANGE ON SEDIMENTATION

Climate change has a significant effect on various hydrological processes in a large river basin. The assessment of these processes is also useful for water resource management and long-term sustainability of any hydrological project. In this study, an attempt has been made to quantify the effects of climate change on sedimentation rate in the Pong Dam lake. Two representative concentration pathways (RCPs) – 4.5 and 8.5 for the two future periods of mid-century (MC) (2021–2050) and end-century (EC) (2071–2100) are considered. Differences in scenarios are compared with the present scenario. The comparisons shown in Table 6 clearly indicate that the sedimentation rate will increase in the future due to increase in extreme events and increase in flow. Hence, dredging or desilting in the reservoir area may be required. Calculations have been undertaken assuming that there are no structural changes made upstream and to Pong Dam lake.

[2] Sedimentation rate is calculated based on 38-year data (1974–2012).
[3] Sedimentation rate is calculated based on modelling data (1974–2012).

Table 6 Comparison of Annual Sedimentation Rate (Mm^3/year) for the Different Scenarios

S.No.	Scenario	Sedimentation Rate (Mm^3/year) – Live Zone of Pong Reservoir	Sedimentation Rate (Mm^3/year) – Dead Zone of Pong Reservoir	Total Sedimentation Rate (Mm^3/year)
1.	Present Scenario	16.77	6.37	23.14
2.	RCP 4.5 (moderate emission scenario; assumes climate policy intervention to transform associated reference scenarios) mid-century	17.81	6.37	24.18
3.	RCP 4.5 (moderate emission scenario; assumes climate policy intervention to transform associated reference scenarios) end-century	19.45	6.37	25.82
4.	RCP 8.5 (a scenario of comparatively high greenhouse gas emissions and does not include climate policy interventions) mid-century	19.74	6.37	26.11
5.	RCP 8.5 (a scenario of comparatively high greenhouse gas emissions and does not include climate policy interventions) end-century	27.49	6.37	33.86

HOTSPOT OF SEDIMENTATION

Spatiotemporal datasets have been analysed using Landsat and Sentinel images for the Pong Dam lake. This method is based on the extraction of open-water features in a wetland ecosystem through the variation of spectral signatures of different features and various indices. Normalized Difference Turbidity Index (NDTI) is used to determine turbidity of the water using the spectral reflectance values. As the turbidity level of water increases due the increase in suspended particles in the water, the reflectance of the red band becomes more than that of the green band. These techniques were used to identify hotspots of sedimentation within Pong Dam lake and the same is shown in Figure 48 and Figure 49 for different years. Turbidity is highest in the monsoon and post-monsoon seasons in the catchment. Heavy rainfall in monsoon season results in erosion, flood and landslides, which in turn results in lot of loose soil and debris flowing down the river and getting collected in the reservoir. These hotspot areas are more prone to sedimentation.

Turbidity can be defined as the cloudiness of water or interference in passage of light caused by suspended materials. The greater the amount of total suspended solids in the water, the higher the measured turbidity. Causes of turbidity include soil erosion, waste discharge, urban run-off and algal growth. Turbidity is mainly caused by suspended sediments in surface waters. Wavelengths between 600 and 800 nm were most useful for determining suspended sediments in surface waters (Ritchie et al., 1976). Sediment load is an important environmental parameter used in determining water quality (Kuo & Cheng, 1978). It may serve as a surrogate contaminant in agricultural watersheds since phosphorus, insecticides and metals adhere to fine sediment particles.

The water turbidity was estimated using the Normalized Difference Turbidity Index (NDTI) and classified into three classes, i.e. low, moderate and high, on the basis of mean and standard deviation of Landsat satellite images of the Pong Dam lake. Land/water interface was identified and masked so that only water would be analysed. Pixel values corresponding to land were set to zero as a result of the masking function. Only water-spread in the river was extracted from the Landsat image, and it was rectified for the modelling. The Normalized Difference Turbidity Index (NDTI) model was run on the image in order to enhance the image quality and the resulting image is shown in Figure 50. Mean and standard deviation values were computed using the statistics of the image with the help of the software. Values for low, moderate and high turbidity were calculated using the following formulas:

- Low = Mean − Standard Deviation
- Moderate = Mean + Standard Deviation
- High = more than moderate

Accordingly low, moderate and high values were assigned to the images and converted in GIS environment. Turbidity of Pong Dam lake has been computed for years 2013 to 2020. It is evident from the analysis that the main stream of Beas river is the main contributor of sediment to the wetland (Figure 50). Maximum accumulation of suspended particles is observed at the outlet of the Beas river into the wetland and at the base of the dam. Baner Khad contributed the least till year 2013 and post 2013 it started contributing to the suspended particles to Pong Dam lake. Gaj Khad and Dehar Khad also contribute to the Pong Dam lake but their contribution is quite less in comparison with main Beas. Deep brown colour within Pong Dam lake indicates maximum suspended particles.

SEDIMENT-CONTRIBUTING STREAMS

Stream channels are dynamic features of a landscape, changing their size, shape and bed material with time, in accordance with changes in water flow and sediment load. Catchment clearing and ‘river training schemes’ result in indirect mobilization of sediment into stream systems. Sediments may also enter streams as a result of other human activities such as the construction of dams and mining activity within a catchment. The construction of roads is known to be a major contributor of sedimentation of waterways. In rivers and creeks, sediment exists in two forms–suspended material and deposited material. Usually, it is the very fine sediment (silt and clay) that is suspended and courser sands get deposited. Under high flows, sand may enter the suspended load and under low flows, silt and clay may settle onto the stream bed. Figure 48 shows the stream sediment load, which in turn helps in understanding the major contributor of sedimentation in the catchment. It is evident from Figure 48 that major contribution areas are either the high slope areas or near urban areas. The same phenomenon is observed in different climate change scenarios (Figure 49).

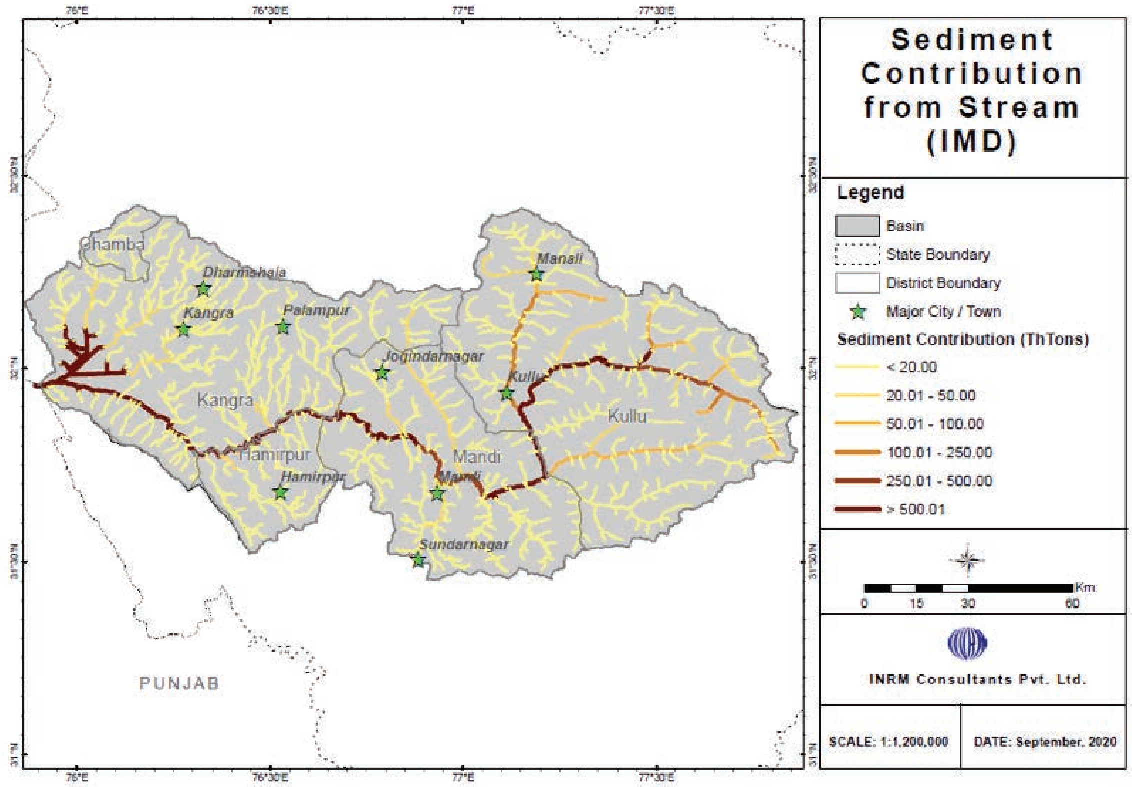


Figure 48 *Sediment Contribution from Streams using SWAT model – Present Scenario (Source: INRM)*

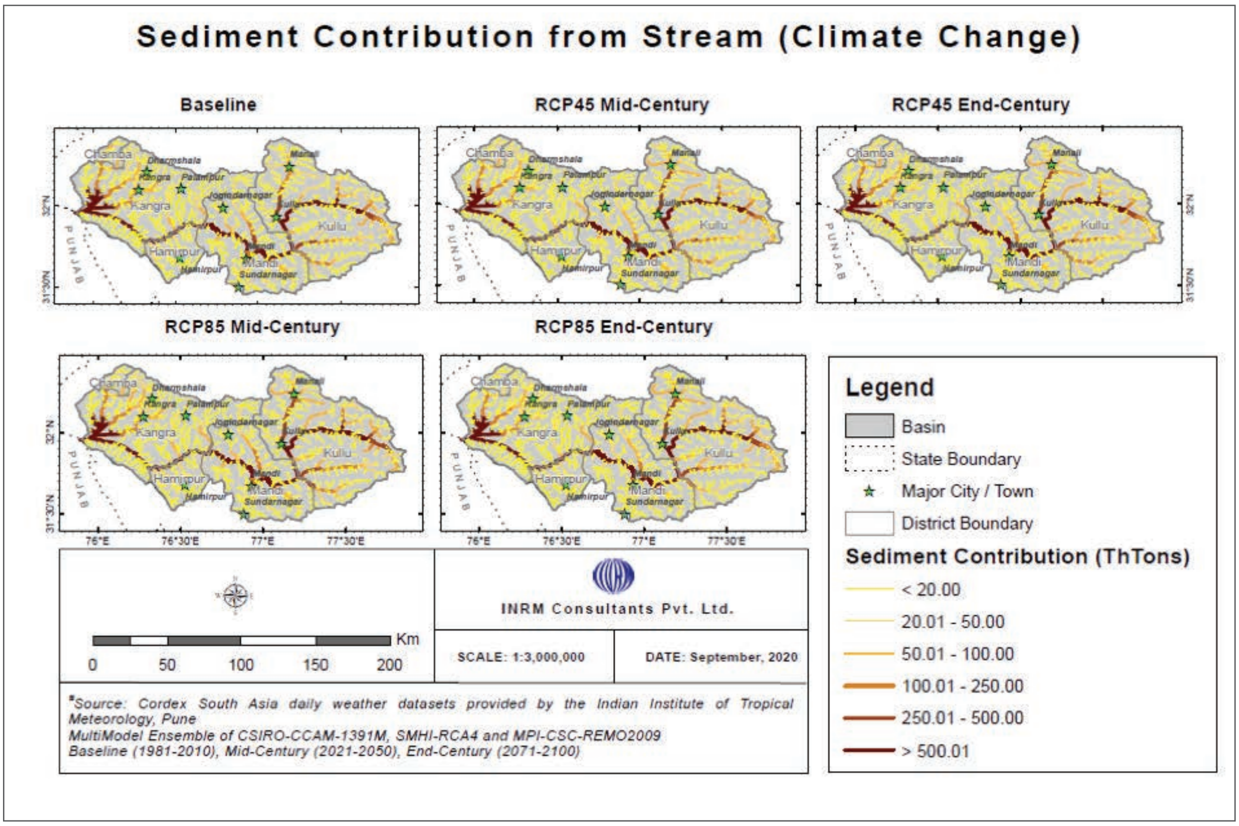


Figure 49 *Sediment Contribution from Streams using SWAT model – Climate Change Scenarios (Source: INRM)*

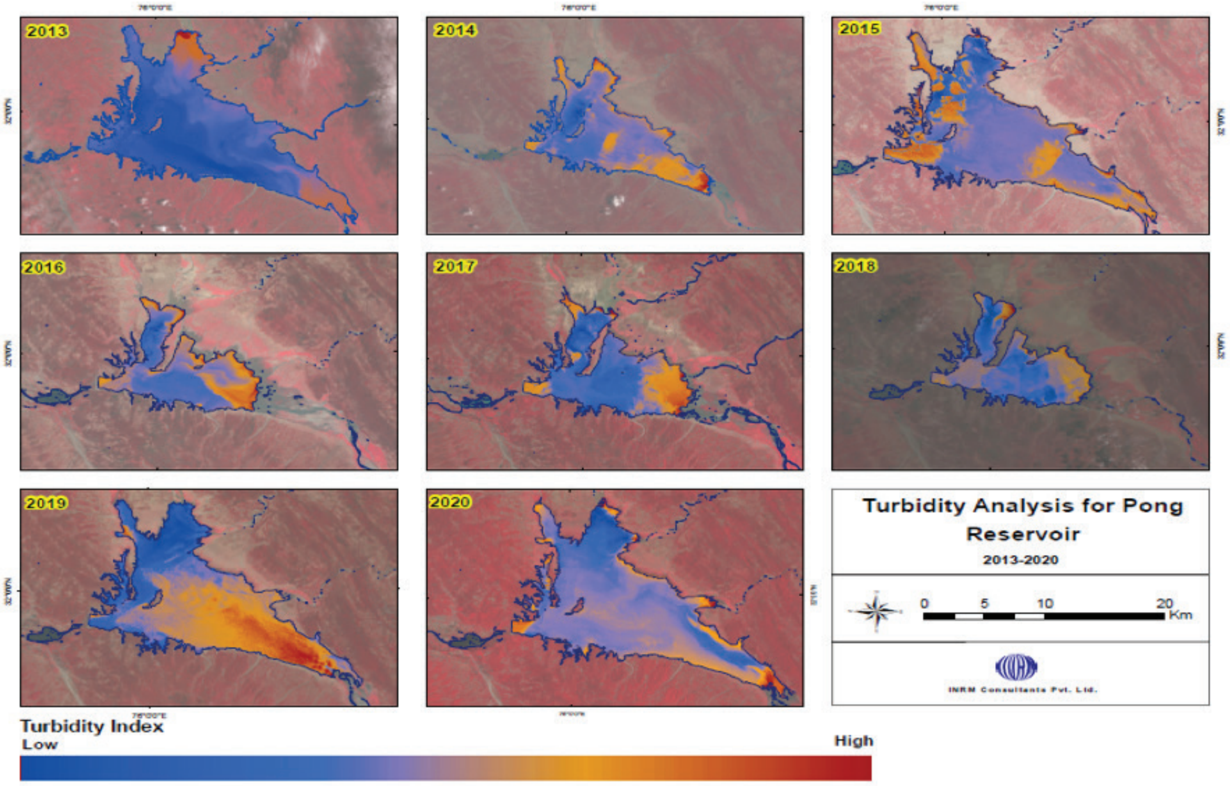


***Figure 50** Turbidity Analysis of Pong Dam lake - Post-Monsoon (Source: INRM)*

WATER QUALITY

Ever-increasing population, urbanization and modernization are posing problems of sewage disposal and contamination of surface waters like lakes and wetlands. Natural water gets contaminated due to weathering of rocks, leaching of soils and mining processing, etc. Land use change and longer growing seasons could increase the use of fertilizers with subsequent leaching to watercourses, rivers and lakes, increasing the risk of eutrophication and loss of biodiversity.

Water quality can be assessed by various parameters such as BOD, temperature, electrical conductivity, nitrate, phosphorus, potassium and dissolved oxygen (DO). Heavy metals presence in fresh water is of special concern because they produce chronic poisoning in aquatic animals. Harmful algal blooms are becoming increasingly common in freshwater ecosystems globally. Pollution by plastic debris is an increasing environmental concern in water bodies where it affects open water.

Monitoring of water quality parameters is important to understand the interactions between parameters and their effect on aquatic life, their growth and health. Each water parameter individually may not cause an alarming situation, but several parameters together can reveal dynamic processes taking place in the wetland. Periodic water quality monitoring can help the wetland authority to note changes and make decisions fast so that corrective actions can be taken quickly. The wetland authority can discuss some of the water quality parameters and the potential threats to aquatic life as well as help in educating the farmers.

Chemicals and nutrients can enter a wetland through surface water and sediment or through groundwater. Water quality parameters collected from various sources are presented in the table that follows. The data presented in the table is of the water sample collected by CIFRI in 2020. Intercomparison between the years cannot be done as temporal information is neither consistent nor available for many years. Some important water quality parameters and their impact on aquatic life are discussed below.

CARBON DIOXIDE (CO_2): Carbon dioxide (CO_2) in ponds is primarily produced through respiration by fishes and the microscopic plants and animals that constitute the pond biota. Carbon dioxide levels (and toxicity) are highest when DO levels are lowest. Thus, dawn is a critical time for monitoring DO and CO_2. High CO_2 concentrations inhibit the ability of fishes to extract O_2 from the water, reducing the tolerance to low O_2 conditions and inducing stress comparable to suffocation. Carbon dioxide concentrations above 60 ppm may be lethal. In an emergency, CO_2 can be removed by adding liming agents such as quicklime, hydrated lime or sodium carbonate to the pond water.

NUTRIENTS: Many water bodies suffer from excessive amounts of nitrogen and phosphorus from barnyards, crop fields, septic systems and waterfowl. Nitrogen is usually present in ponds as ammonia or nitrate, while phosphorus occurs as phosphate. Ammonia usually originates from animal or human wastes directly entering the pond. It is extremely toxic to fish and other aquatic life and the pond's health. Both nitrogen and phosphorus can be readily used by aquatic plants and algae, which may lead to excessive growth. The death of large amounts of aquatic plants or algae, naturally or as a result of herbicide use, consumes dissolved oxygen from the water and may lead to fish kills. Nitrate-nitrogen concentrations above 3 mg/L are indicative of pollution. Phosphate concentration as low as 0.01 mg/L, may be sufficient to increase plant and algal growth. Excessive amounts of nitrate can also be dangerous for drinking water. Dairy cows should not drink water with nitrate concentrations in excess of about 23 mg/L measured as nitrate-nitrogen.

BOD: The biochemical oxygen demand (BOD) is the amount of oxygen taken up by microorganisms that decompose organic waste matter in the water. This is an indication of both sewage and industrial pollution. The optimum BOD level for aquaculture should be less than 10 mg/L. If the effluent water BOD is less than 10 mg/L it can be considered good for fish culture. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low dissolved oxygen - aquatic organisms become stressed, suffocate and die.

COD: The chemical oxygen demand (COD) of water represents the amount of oxygen required to oxidize all organic matter, both biodegradable and non-biodegradable, by a strong chemical oxidant. This is an indication of both sewage and industrial waste. The ideal value of COD should be less than 50 mg/L. A higher concentration of COD indicates a higher level of pollution in water which is bad for fish health.

CONDUCTIVITY: Generally, the amount of dissolved solids in water determines the conductivity. Conductivity actually measures the ionic process of a solution that enables it to transmit current. According to WHO standards, the value should not exceed 400 μS/cm. The current study indicates that conductivity in the study area is 234.4 μS/cm, which is within the permissible range.

TOTAL DISSOLVED SOLIDS: Total dissolved solids (TDS) denote mainly the various kinds of minerals present in water. The permissible value recommended for TDS is 500 mg/L prescribed by BIS and FAO. The present study observed that Pong Dam lake water samples had a low TDS of 110 mg/L in year 2020 which indicates that the water is less mineralized. The TDS changes the mineral content of the water, which is important to the survival of many animals. Elevated total dissolved solids can result in the water having a bitter or salty taste. Also, dissolved salt can dehydrate the skin of aquatic animals, which can be fatal. It can increase the temperature of the water causing many animals to die.

MAGNESIUM: The concentration of magnesium in the study area was 6.63 mg/L in year 2020. The maximum permissible limit of magnesium is 50 mg/L. Magnesium is often associated with calcium in all kinds of water but its concentration remains generally lower than that of calcium. Decrease in level of magnesium reduces the phytoplankton population.

PHOSPHATE: The level of phosphate in aquarium or pond water encourages algal growth. Phosphorus is required for plant growth but excessive levels can mean increased growth of plant life. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate stimulates the growth of plankton and aquatic plants which provide food for fish. This may cause an increase in the fish population and improve the overall water quality. In the study area, the level of phosphate was within thepermissible range.

DISSOLVED OXYGEN: As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1–2 mg/L for a few hours can result in large fish kills.

Year-wise water quality parameters gathered from various sources are given in the table below.

Parameters/-Years	Permissible Range	1990-1991	1992-1993	1993-1994	1994-1995	2006	2007	2008	2009	2010	2011	2012	2013	2014	2020
Water Temperature (°C)	Species dependent	23	22	22.5	24	24	21	17.5	24.1	16.8	22.1	21	19.9	23.2	26.5
Transparency (cm)		234	201	168											258
pH	6.5–8.5	8.05	7.6	7.55	7.45	7.95	8.3	7.9	8	8.1	8.2	8.6	8.5	8.2	8.5
DO (mg/L)	>5 mg/L	8.8	9.05	8.2	7.4	8.4	7.8	8.6	8.5	9.3	8.1	7.4	7.5	5.6	6.86
Free CO_2 (mg/L)		1	3	3	2									3.5	
Total Alkalinity (mg/L)	200 mg/L	81	71	81	66									165	81.8
Calcium (mg/L)	75 mg/L			26.8	25.6										21.2
Magnesium (mg/L)	50 mg/L			4.64	5.1										6.63
Phosphate (mg/L)	0.005 to 0.05 mg/L	0.15	0.16	0.21	0.25										0.03
Silicate (mg/L)	5 to 25 mg/L			1.69	2.04										6.34
Organic matter (mg/L)		3.9	3.8	4.6	3.8										
Hardness (mg/L)	300 mg/L	67	72	113	101										77.6
Total dissolved solids (mg/L)	500 mg/L		77.4	100.95	78.9									126	110
Specific Conductivity (µS/cm)	400 µS/cm	164.7	146.1	190.3	153.95	211	168	191	188	244	165	354	185	187	234

MEASURES TO SUSTAIN AND MAINTAIN HYDROLOGICAL FUNCTIONING OF WETLANDS

This section presents adaptive capacity and operational policies to highlight the performance, i.e. reliability as well as vulnerability in water supply of Pong Dam lake during climate change scenarios. Reservoirs/wetlands are a major component of most water supply systems utilizing river resources. The primary objective is to regulate natural river flow fluctuations by storing the excess water during high flow periods which is then released during low flow periods to meet domestic, industrial, agricultural and other demands served by the system. The planning of reservoirs using historical run-off data observed at the reservoir site is the best option available to the analyst but could be problematic if the operational run-off situation of the reservoir differs radically from the planning situation, e.g. with predicted climate change that might further vary the amount and increase the variability of reservoir inflows.

The realization that climate change will affect future inflow series and hence the performance of reservoirs to meet its obligations has led to the intensification in assessment of these impacts as a precursor to the development of effective mitigation and adaptation strategies (Nawaz & Adeloye, 2006; Fowler et al., 2003; Li et al., 2009; Adeloye et al., 2013). In general, most of these studies have reported deteriorating performance with climate change (e.g. lower reliability, increase in frequency and/or magnitude of water shortages) although as recently demonstrated by Soundharajan et al. (2016), there are huge uncertainties associated with both the magnitude and sign of these impacts. Such unsatisfactory situations call for concerted adaptation and/or mitigation efforts which might require that either the facilities are expanded (e.g. building new reservoirs, developing other sources such as groundwater) or operational improvements are introduced for existing facilities. New builds for capacity expansion are often controversial, requiring long gestation periods and can have unwanted social and environmental consequences. In contrast, devising improved operational practices is much quicker and has been proven to be effective for significantly curbing systems vulnerability (Eum et al., 2011).

Ever-increasing population, urbanization and modernization pose problems of sewage disposal and contamination of surface waters. Natural water gets contaminated due to weathering of rocks, leaching of soils mining processing, etc. Land use change and longer growing seasons could increase the use of fertilizers with subsequent leaching to watercourses, rivers and lakes, increasing the risk of eutrophication and loss of biodiversity. Pollution by plastic debris is an increasing environmental concern in water bodies where it affects open-water, shoreline and benthic environments. For over thousands of years, human settlements and civilizations have originated, concentrated and thrived around different types of water bodies (Bhateria et al., 2016). It is known that water bodies have played a crucial role in the growth and development of human society. However, it is paradoxical that they have undergone degradation in modern times due to various anthropogenic activities like pollution, encroachment, eutrophication, illegal mining activities, ungoverned tourist activities and cultural misuse (Adeloye et al., 2013).

Wetlands are important features in the landscape that provide numerous beneficial services for people, wildlife and aquatic species. Some of these services or functions, include protecting and improving water quality, providing fish and wildlife habitats, storing floodwaters and maintaining surface water flow during dry periods. These valuable functions are a result of the unique natural characteristics of wetlands. Wetlands are among the most productive ecosystems in the world, comparable to rainforests and coral reefs. An immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish and mammals can be part of a wetland ecosystem. Climate, landscape shape (topology), geology and the movement and abundance of water help to determine the plants and animals that inhabit each wetland.

The Pong Dam lake is one of the largest man-made wetlands in Himachal Pradesh. In addition to local people, the migratory graziers like Gaddies and Gujjars also benefit from the wetland. Some of the common major drivers/factors responsible for the degradation of any wetland are stated below, some of which hold true for Pong wetland:

- Release of toxic pesticides from agriculture
- Tilling for crop production
- Population pressure
- Grazing
- Human sewage
- Nutrient influx
- Dumping of crop waste
- Weeds and eutrophication
- Solid waste pollutants like polythene
- Entry of waste water
- Lack of maintenance
- Introduction of non-native species
- Increased siltation
- Bathing of domestic animals
- Dumping of animal carcass
- Weak policy
- Poor law enforcement
- Inappropriate governance
- Limited consideration of wetlands in national and local-level land use planning

Due to a growing recognition of the importance of wetlands in environmental and ecological functions, the rate of sedimentation needs regulation in the Pong Dam lake through afforestation and adoption of agroforestry practices in the agricultural field. Frequent flooding in the past years has posed a serious threat to wetland ecology, biodiversity of the region and human settlements downstream of the dam. Hence, a few corrective actions and preventive measures from concerned authorities and stakeholders are needed. Some of the proposed corrective actions and preventive measures are listed below:

- Since climate change is an inevitable phenomenon, it calls for an early warning and flood warning system at the basin scale
- Periodic desilting of waterbodies and reservoirs
- Installation of silt traps at the mouth of the wetland
- Proper waste management system
- Afforestation

Apart from the issue of sedimentation, which gets aggravated due to anthropogenic activity and climate change, there are few other issues which need immediate intervention. Although the water quality standard of the catchment is within permissible range, a few parameters show deterioration, e.g. dissolved oxygen. Dissolved oxygen has drastically reduced over the years. As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress and this could disturb the complete food chain and ecology of the wetland.

Also, over the years it is observed that many new species of resident and migratory birds have started nesting in the Pong Dam lake. A few of the migratory birds like bar-headed geese, northern pintails, common coots and great cormorants travel to thia wetland after covering a long journey from Russia, Siberia and Mongolia. However, the climate change trend shows an increase in temperature in the near future, which will adversely affect the nesting timing and span of migratory and resident birds. Hence, to mitigate the ill effects of the increase in temperature, more plantations need to be done in and around the wetland. This will also help in arresting the sediment and erosion from nearby areas. There is an emergent need to ensure appropriate protection of biodiversity, particularly the waterfowl species in the wetland.

Future vigilance and coordinated efforts by both individuals and government is required to protect the Pong Dam lake. Therefore, it is suggested that various government agencies must effectively coordinate to reinforce laws for wetland sustainability at both local and national levels.

Appendix III gives an overview of the status of and trends in components, processes and services of Pong Dam lake. A table on analysis of risks of change in ecological character is given in Appendix - IV, with likely threats and recommendations. The following is a summary of the risks of change in ecological character with associated threats and the recommended mitigation strategy:

- Climate change impact due to CO_2 emission may result in frequent floods, influx of debris, warm nights/days and unequal distribution of rainfall. The recommended mitigation strategy consists of afforestation, generation of alternative livelihood options, desilting of the reservoir and installation of silt traps.
- Turbidity due to excessive sedimentation can result in less sunlight penetration, resulting in modification or prevention of sunlight penetration through the water due to high concentrations of particulate matter. This causes the shallow part of the wetland to fill in faster and smothers benthic habitats. This impacts both underwater organisms and their eggs. The recommended mitigation strategy consists of afforestation, desilting of the reservoir, installing silt traps at the mouth of the wetland and providing buffer strips near the wetland to arrest the excessive sediment.
- Excess nutrients due to excessive usage of fertilizer and pesticide, over-stimulate the growth of aquatic plants and algae which clogs water ways and blocks light to deeper waters while the organisms are alive. When the organisms die, they use up dissolved oxygen as they decompose, causing oxygen-poor waters that support only diminished amounts of marine life. Pesticides can contaminate soil, water, turf and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to a host of other organisms including birds, fish, beneficial insects, and non-target plants. The recommended mitigation strategy consists of restricted use of pesticide and fertilizer, providing buffer strips near the wetland to arrest excessive sediment and nutrient, alternative livelihood options and zonation within the wetland.
- Interference of humans and overlapping human interests can adversely impact the ecology/habitats of wetlands. The mitigation strategy would involve dividing wetlands into zones with restrictions and creating and promoting alternative livelihood options like ecotourism, fishery, beekeeping, livestock farming and horticulture.

INTERLINKAGES AND TRADE-OFFS

Wetlands are dynamic ecosystems, changing naturally over time as a consequence of processes such as erosion, sedimentation and flooding. However, human activities either within the wetland or in the catchment in which they are situated can alter these natural processes or accelerate the rate of change, threatening the wetland's continued existence. Agriculture is not the only activity that damages wetlands. Populations around wetlands often grow quickly, leading to pressure on natural resources. Climate change is also expected to escalate the pressure on wetlands.

More variable rainfall and increase in temperature could affect the natural replenishment and change the ecology of Pong Dam lake; risk of flooding from excessive melting of snow, deforestation and quarrying are another threat in some regions.

The wise use of wetlands is expected to contribute to ecological integrity as well as to secure livelihoods, especially of communities dependent on their ecosystem services for sustenance. In this section, an attempt is made to provide a broader conceptual framework capable of examining the goals of wetland management, poverty reduction and sustainable livelihoods. Also an attempt is made to build a concept for assessing the interlinkages between ecosystem services and livelihoods. There are various trade-offs dependent on Pong wetland and there is a need to conceptualize the interlinkages. Various interlinkages will be established since there are multiple actors and players dependent on wetlands. Sustainable ecological balances need to be established as best management practices for overall benefit of the community at large.

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. There are several challenges to establishing these parameters for trade-offs. An integrated water resource management approach should be adopted while developing management strategies for wetlands. If local people are fully included in these discussions, the results can be very successful. Involving local communities and wetland users in the process of establishing trade-offs is essential for success. Once these have been established, they should be developed into management plans that integrate the needs of local people with conservation goals. Local people in collaboration with research institutes and government agencies should decide which parts of the wetland could be used for fishing and how access should be rotated to allow stocks to recover. Local fishermen should receive training in fisheries management to reduce the risk of overfishing.

Development of ecotourism should be encouraged so that an alternative source of income for some communities gets generated which would help in making them less dependent on the reserve's resources. Involving local people throughout the process will allow them to have a stronger say in the management of the wetland. Once the outcome is implemented as a plan it would be a mutually agreed solution, representing a balance with regard to locally and politically acceptable wetland use and state and national environmental laws. Selected/shortlisted practice may not be the best option in terms of conservation or development, but this process can prove to be the best way to integrate these competing demands.

Human societies are fundamentally linked to wetlands from the core human requirements for water and food to the choices and trade-offs they make and the governance systems that influence their behaviour in and around wetlands. Livelihood strategies of communities living in and around wetlands also influence their ecological character. This calls for wise use of wetlands which can contribute to ecological integrity, and secure livelihoods, especially of communities dependent on their ecosystem services for sustenance.

Wetland loss and degradation impact human well-being, and the existence of poverty may lead to interventions that have an impact on wetlands. These impacts can be direct such as over-exploitation of a natural resource that reduces livelihood options (Nowak, 2008) and absence of sanitation that forces people to use wetlands for waste disposal, or indirect actions such as destructive catchment agricultural practices leading to changes in wetland sedimentation (Kgathi et al., 2006). The services that a wetland provides stem from its biodiversity and ecological character.

While the farmers within a wetland are often the focus of attention for those seeking to protect wetlands, agricultural practices in areas upstream also affect the quality and quantity of water flowing into them. Agricultural practices may also increase surface run-off and soil erosion, thereby increasing the amount of sediment entering a wetland. Fishery is another source of livelihood, but it is observed that there is decline in the fish yield as seen after the 1988 flood. The favourable conditions and parameters for fish growth and yield were listed by the Central Inland Fisheries Research Institute (CIFRI). It was informed by CIFRI that the current yield of fish is far less than the potential growth and yield in the Pong wetland. The major parameters on which fish yield and growth depend are listed below:

- Temperature
- Dissolved oxygen
- Nutrient loading
- Turbidity

Discussion with CIFRI shows that these parameters are of great importance. These parameters were examined under present and future climate conditions and it was inferred that increase in temperature in future shall help in increasing the fish yield in the Pong Dam lake basin. But flood and extreme flows like that of 1988 will adversely affect the growth. Due to sudden and flash flood events in future scenarios, adverse impact can happen on the yield of the fish. Damages from these flash floods can be reduced by adopting techniques like planting, terracing hillsides to slow down the downhill flow, the construction of flood ways and construction of levees, lakes, dams, reservoirs and retention ponds. Overall growth of fish yield will help in attracting migratory birds which depend on the fish as food but temperature increase shall impact or reduce the nesting time of migratory birds. Also, fishery can be developed as an alternative source of livelihood. Fish culture and fishery have not attained their maximum capacity, and fish culture can be increased and it can become an alternative source of livelihood (as stated by CIFRI during an online interaction).

Sedimentation analysis shows that sedimentation will increase in future which can be attributed to various climate change and anthropogenic activities taking place in the Pong basin. This increase in sedimentation is not good for the reservoir, flood protection, etc., but the sediment deposited makes the land fertile which when exposed due to less inflow in the reservoir can be utilized for agriculture. But it should be ensured that usage of pesticides and fertilizers is restricted in these areas as it can adversely impact the wetland ecology and the water quality.

Increasing temperature, changing precipitation patterns and water resource availability, and increasing atmospheric levels of CO_2 will have an impact on sustainability of major sectors such as agriculture, forestry and fisheries. The impact may vary across regions, zones and subsectors. Therefore, alongside mitigation initiatives, adaptation to climate change needs to be undertaken to safeguard the interests and well-being of local communities, especially the poor and vulnerable. Some of the broader mitigation and adaptive strategies which can help in sustenance of the ecology of the wetland are listed below:

- Create and maintain a vegetated riparian buffer or buffer zone of grass that can help in reducing sediment load in the overland flow entering the wetland.
- Install/create devices such as riparian buffers, mesh fences, sediment retention ponds and sediment traps to reduce sediment pollution in the wetland.
- Avoid direct discharge of run-off in the wetland/river. Sediment traps and eco/bio STP should be installed at least before discharging run-off in the wetland to reduce and remove harmful pollutants from water.

- Carry out afforestation in the whole catchment as it helps in reducing impact of climate change and associated risks. Afforestation helps in arresting the soil erosion and also helps in reducing the flow velocity and temperature of the region.
- Take up watershed management works such as construction of check dams, check walls, and bioengineering works in the catchment to reduce the silt load in the wetland and also to store excessive water for utilization in non-monsoon seasons.
- Make habitat improvement to attract more migratory and local species of birds.
- Use zonation of the wetland, so that conflicting interests of various actors do not disturb the ecology and create imbalance in the system.
- Make income generation activities for local people a part of planning activities. Alternative livelihood options like horticulture, beekeeping, sericulture, fishery in ponds, dairy farming and tourism should be promoted and encouraged by the government. In case of reduced agriculture income, livelihood can be sustained.
- Implement trapping of debris of construction waste and landslide at Dehar Khad, Gaj Khad and Baner Khad before they join Pong Dam lake. Similar trapping should be done upstream of Pandoh dam.
- Carry out desilting of Pong and Pandoh at regular intervals.
- Minimize usage of pesticides and fertilizers on all agricultural land near the Pong wetland.
- Install more flow and weather monitoring stations, and record data regularly so that it can be used for an early warning system.
- Customize dam regulations and rules according to the flow monitoring and early warning system.
- Spread awareness among local people through education with respect to management issues of wetlands.
- Make conservation and restoration of wetlands the focus of the Wetland Conservation Programme, with the active participation of the local community at the planning, implementation and monitoring levels.
- Make a wetland and river health analysis and report card annually or biannually to maintain a health card of the river and wetland. By doing this, any deterioration can be analysed and seen at a very early stage. A list of some important parameters of both Ecological Health Index (EHI) and Ecological Quality Index (EQI) is given in Appendix II.

CONCLUSION

Himachal Pradesh is one of the most water surplus states with respect to rainfall and per capita water availability in India. It is projected that the state will receive more water due to impact of climate change. However, ecosystems are likely to be adversely affected by increasing temperatures, changes in rainfall patterns, spread of pests and weeds, changed fire regimes triggered by increasing temperature, etc. Higher temperatures, possible changes in precipitation patterns and glacial chemistry are likely to affect Himalayan ecosystems.

It is evident from this study that rainfall in the basin will increase in the future. Increase in frequency of extreme events will adversely impact the ecology of the area, if timely corrective actions are not taken. Rise in future temperature, both minimum and maximum, will lead to increase in the frequency of flood events in the state as well as in the study catchment. As temperature determines the number and types of animals and plants that live in or depend on wetlands and waterbodies, rising temperature can alter the habitat survival and influx of migratory species. Climate change is likely to affect perennial aquaculture, fisheries, changes to water currents and nutrients, and changed rainfall patterns. There are specific and different threats to local fisheries and aquaculture. Aquaculture is likely to be impacted by climate change through higher temperatures, water availability and erosion of river bed.

It is also apparent from the study and analysis presented that surface run-off will increase, bringing more water to the area. But unplanned anthropogenic changes in the area can harm the catchment more. There should be proper planning and management keeping in view the changes evident from the study. In the present study, as a first step, a detailed climate change analysis and a detailed climate risk assessment have been performed using the available data to help identify the hotspots.

Pong Dam lake is one of the important sources of livelihood for the local communities. Fishery and agriculture are two main sources of livelihood source in the area. But fishery can get impacted due to climate change as fish yield is dependent on temperature, concentration of the suspended and settled solids and chemical parameters like pH, alkalinity, hardness and metals. It is apparent from the results that concentration of suspended particles will rise in future, which would adversely affect the growth and yield of many fishes which are found in Pong Dam lake area.
Increase in run-off will cause more erosion and deposit more sedimentation in the wetland and other structures. Sediment deposits in rivers can alter the flow of water and reduce water depth, which makes navigation and recreational use more difficult. In addition, they reduce the carrying capacity of the river which can cause more frequent flooding. Sediments can clog fish gills, reducing resistance to disease, lowering growth rates and affecting fish egg and larvae development. Nutrients transported by sediments can activate blue-green algae that release toxins which is harmful for aquatic life and habitats. Murky water prevents natural vegetation from growing in water. Sediment in stream beds disrupts the natural food chain by destroying the habitat where the smallest stream organisms live and causes massive declines in fish populations. The sediment in wetlands adversely impacts the ecological health of the wetland and in turn impacts the influx of the habitats and migratory birds. Apart from the impact on ecology and biodiversity of the Pong Dam lake, sedimentation will also impact reliable water supply, hydropower and flood mitigation.

Excessive sediment deposits on the river/stream bed can significantly alter and degrade habitat. Some animals are dependent on the rocky bottoms of streams while others live in deep sandy pools or around woody debris. Sediments fill the spaces between stones that invertebrates live in and in extreme cases can bury woody debris, stony substrates (gravels and cobbles), root mats, fill pools and channels. This reduces the amount of invertebrate habitat/cover and spawning grounds (a place to lay eggs) for fish. An increase in the amount of sediment deposited on the river/stream bed can also significantly change the flow and depth of rivers or streams over time and infill lakes and estuaries. Natural cleaning processes where the water flows through the gravel bed of a stream and interacts with the microbes living on stone surfaces, removing nutrients and some pollutants, can also be short circuited by excessive sediment deposits.

There are no definite solutions to wetland management, since each wetland varies in terms of its climate, ecosystem, pressures and users. Instead, wetlands need local-level policies and responses. How wetlands should be used and managed is ultimately determined by local stakeholders in association/consultation with the concerned authorities. These stakeholders include not only local communities and users of the wetland but also local authorities and people living upstream and downstream. It is vital to involve local people in wetland planning, management and decision-making processes, and empower them to use wetlands. Local people bring considerable traditional knowledge on the function and management of wetlands. The involvement of local people is also vital for building a consensus on how resources should be used and protected. Conservation initiatives without local acceptance will invariably fail, and confrontational action may be needed to enforce them. Management options that local people have developed and agreed upon shall in many cases survive over the longer term. However, it is also true that many traditional management systems are breaking down under the pressures of changing current and future needs.

It is also suggested that zonation within the wetland will help in overall development and protect the overlapping/conflicting interests of various stakeholder. Early and timely adaptation will be influenced by the extent to which climate change factors are incorporated into sectoral and regional planning. Sectors dependent on natural resources are particularly vulnerable to climate change.

The importance of wetlands in balancing ecological concerns has brought renewed focus to the Pong Dam lake. This calls for sedimentation balancing through afforestation and putting the silt trap at the mouth of the confluence of the river and wetlands. Water quality balancing should be done for thriving aquatic life by trapping the waste near the source itself. Afforestation would also ensure reduction in erosion and temperature which would help in influx of migratory birds, thus protecting the biodiversity of the region. A combined effort of the government and local bodies is thus required for sustainability and maintenance of this beautiful region of Pong Dam lake.

Risk reduction measures can be implemented by any entity that may be affected by or is at risk from a changing climate, land use and sedimentation perspective of the Pong Dam lake. The most effective risk reduction occurs when all parties from the state government and wetland authority/dam authority to community agencies and at-risk individuals are aware of each other's actions and coordinate them effectively. No entity can act alone and expect to be successful. Working together maximizes risk reduction in every phase of the risk reduction process. Stakeholders must understand their roles and responsibilities to ensure effective risk reduction and efficient management. Strategies, frameworks, initiatives, plans and procedures must be flexible and adaptable to the unique and dynamic environment created keeping all stakeholders in view. One of the initial critical steps is identifying the population at risk and livelihood impact, and understanding each stakeholder's mission, objectives, obligations and expectations for risk reduction. Ensuring effective communication among stakeholders will improve coordination among the various entities.

Thus, this effort requires adoption of a long-term strategy of adapting, observing and evaluating. Such an elaborate effort requires an equally elaborate information framework (knowledge base) on GIS platform to be designed and implemented. This system not only helps in integrating all the past information but can also be used as an interface for analysis, implementation, evaluation, feedback to policymaking and information dissemination to stakeholders as advisories or feedback mechanism. With the availability of such a system, it will also become possible to achieve convergence of scales which is very important, since climate projects are at macro-scale but the action has to be at the local scale.

Photo credit: KunalBharat.GIZ

REFERENCES

Adeloye A.J., Nawaz N.R., Bellerby T.J. Modelling the impact of climate change on water systems and implications for decision makers. Chapter 11.Surampali R.Y., et al. (eds.). Climate Change Modelling, Mitigation, and Adaptation. Environmental & Water Resources Institute, ASCE;2013: 299–326.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large Area Hydrologic Modeling and Assessment Part I: Model Development1. JAWRA Journal of the American Water Resources Association, 34(1), 73–89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: A review. Sustainable Water Resources Management, 2(2), 161–173. https://doi.org/10.1007/s40899-015-0014-7

Cai, X., Mckinney, D., & Lasdon, L. (2002). A Framework for Sustainability Analysis in Water Resources Management and Application to the Syr Darya Basin. Water Resources Research - WATER RESOUR RES, 38. https://doi.org/10.1029/2001WR000214Cunderlik J.M., Ouarda T.B.M.J. Trends in the timing and magnitude of floods in Canada. J.Hydrol. 2009; 375(3–4): 471–480.

Chien H., Yeh P.J.F., Knouft J.H. Modeling the potential impacts of climate change on streamflow in agricultural watersheds of the Midwestern United States. J. Hydrol. 2013; 491: 73–88.

DhadwalD.S. WildWings: Pong &Its Birds. Kangra, India: Author; 2011: I–VIII, 1–149.

Durbude D.G., Purandara B. Assessment of sedimentation in the Linganmakki reservoir using remote sensing. J. Indian Soc. Remote Sens. 2005; 33(4): 503–509.

Eum H.I., Simonovic S.P. Integrated reservoir management system for adaptation to climate change: the Nakdong River basin in Korea. Water Resour. Manage. 2010; 24: 3397–3417.

Eum, H.-I., Kim, Y.-O., & Palmer, R. (2011). Optimal Drought Management Using Sampling Stochastic Dynamic Programming with a Hedging Rule. Journal of Water Resources Planning and Management, 137, 1–10. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000095

Fowler H.J.,Kilsby C.G., O'Connell P.E. Modeling the impacts of climatic change and variability on the reliability, resilience and vulnerability of a water resource system. WaterResour. Res.2003; 39(8):1222.

IPCC. Summary for policymakers. Climate Change 2007: the Physical Science Basis. Contribution of the Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2007.

Jain S.K., Agarwal P.K., SinghV.P. Hydrology and Water Resources of India. The Netherlands: Springer; 2007.

Kgathi D.L., Kniveton D., Ringrose S., Turton A.R., Vanderpost C.H.M., Lundqvist J., Seely M. The Okavango; a river supporting its people, environment and economic development. J.Hydrol. 2006; 331: 3–17. doi: 10.1016/j.jhydrol.2006.04.048.

Kumar V., Singh P., Singh V. Snow and glacier melt contribution in the Beas River at Pandoh Dam, Himachal Pradesh, India. Hydrol. Sci. J. 2007; 52(2): 376–388.

Kuo C.Y., Cheng R.Y.K. Laboratory requirements for in situ and remote sensing of suspended material. Technical Report (NASA-CP-145367). Norfolk, Virginia, USA: Old Dominion Univ.; 1978: 29–31.

Li L., Xu H., Chen X. Streamflow forecast and reservoir operation performance assessment under climate change. WaterResour. Manage.2009; 24: 83–104.

Malik M. Wetland degradation: driving force and environmental impacts in the Pong Dam lake, Kangra, H.P. Unpublished M.Phil. Dissertation, Department of Geography, University of Delhi; 2017.

Ministry of Water Resources, C. W. C. (2018). Handbook for Assessing and Managing Reservoir Sedimentation.

Pathania M.S., Gurrala A.K. Economic valuation and causes of degradation of Pong dam wetland of Himachal Pradesh. Int. J.Soc. Sci. 2017; 6(1): 21–29.

Nawaz N.R., Adeloye A.J. Monte Carlo assessment of sampling uncertainty of climate change impacts on water resources yield in Yorkshire, England. Clim. Change.2006; 78(2–4): 257–292.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Srinivasan, R., and Williams, J,R.: Soil and Water Assessment Tool, User Manual, Version 2000. Temple, Tex.: Grassland, Soil and Water Research Laboratory, 2002.

Neitsch S.L., Arnold J.G., Kiniry J.R., Williams J.R. Soil and water assessment tool theoretical documentation version 2005. Grassland, Soil and Water Research Laboratory –Agricultural Research Service, and Blackland Research Center – Texas Agricultural Experiment Station, Temple, Texas, USA; 2005.

Nowak B. Environmental degradation and its gendered impact on coastal livelihoods options among Btsisi' households of Peninsular Malaysia. Development. 2008; 51: 186–192.doi: 10.1057/dev.2008.3.

Soni M.P., Aavudai A., Mukundan R., et al. Application of SWAT model to assess snowpack development and streamflow in the Cannonsville watershed, New York, USA. Hydrol. Process. 2011; 25(21): 3268–3277.

Rahman K., Maringanti C., Beniston M., Widmer F., Abbaspour K., Lehmann A. Stream flow modeling in a highly managed mountainous glacier watershed using SWAT: the Upper Rhone River watershed case in Switzerland. Water Resour. Manage.2013; 27(2): 323–339.

Ritchie J.C., Schiebe F.R., McHenry J.R. Remote sensing of suspended sediment in surface water. Photogramm.Eng. Remote Sensing. 1976;42: 1539–1545.

Shukla S., Jain S., Kansal M., Chandniha S. Assessment of sedimentation in Pong and Bhakra reservoirs in Himachal Pradesh, India, using geospatial technique. Remote Sens. Appl.: Soc. Environ.2017; 8.doi: 10.1016/j.rsase.2017.08.008.

Soundharajan B.S., Adeloye A.J., Remesan R. Evaluating the variability in surface water reservoir planning characteristics during climate change impacts assessment.J.Hydrol. 2016; 538.

Watershed & Reservoir Sedimentation Directorate, Environment Management Organisation, & Water Planning and Projects Wing. (2015). The Compendium on Siltation of Reservoirs, H.P. (2015).

Zampieri M., Scoccimarro E., Gualdi S. Atlantic influence on spring snowfall over the Alps in the past 150 years.. Res. Lett. 2013; 8(3), 034026.

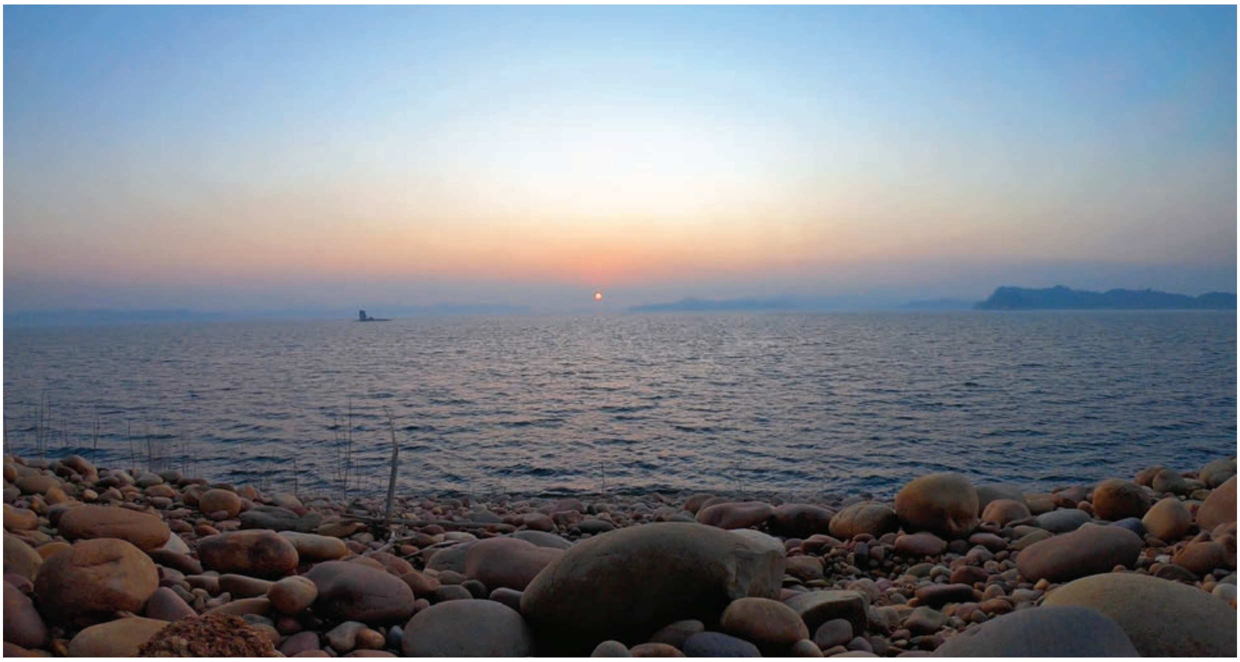


Photo credit: CarrotFilms.GIZ

APPENDIX I

Table 7 Change in Daily Maximum Temperature (°C) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 4.5 Scenario)

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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	**1.5**	**2.8**	**1.9**	**3.4**	**1.4**	**2.6**	**1.6**	**3.1**	**1.2**	**2.1**
Chamba	1.6	3.0	2.1	3.6	1.4	2.6	1.8	3.5	1.3	2.3
Hamirpur	1.3	2.2	1.8	3.0	1.6	2.8	0.9	1.7	1.1	1.6
Kangra	1.5	2.6	1.9	3.3	1.5	2.8	1.3	2.6	1.2	2.0
Kullu	1.5	2.9	2.0	3.5	1.3	2.5	1.7	3.5	1.2	2.1
Mandi	1.5	2.6	2.0	3.4	1.5	2.7	1.3	2.6	1.2	1.9
Data Source: CORDEX South Asia RCM: Multi-Model Ensemble Mean										

Table 8 Change in Daily Maximum Temperature (°C) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 8.5 Scenario)

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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										

Table 9 Change in Daily Minimum Temperature (°C) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 4.5 Scenario)

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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	**1.4**	**2.7**	**1.5**	**2.9**	**1.1**	**2.3**	**1.8**	**3.4**	**1.3**	**2.3**
Chamba	1.5	2.9	1.4	2.7	1.1	2.2	2.2	3.9	1.3	2.4
Hamirpur	1.4	2.6	1.6	2.9	1.2	2.4	1.7	3.3	1.2	2.1
Kangra	1.5	2.8	1.4	2.8	1.1	2.3	1.8	3.5	1.3	2.3
Kullu	1.4	2.6	1.4	2.9	1.0	2.1	1.7	3.2	1.3	2.4
Mandi	1.4	2.6	1.6	3.0	1.1	2.2	1.7	3.2	1.2	2.1
Data Source: CORDEX South Asia RCM: Multi-Model Ensemble Mean										

Table 10 *Change in Daily Minimum Temperature (°C) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 8.5 Scenario)*

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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**	**5.0**	**1.9**	**5.2**	**1.5**	**4.7**	**2.3**	**5.5**	**1.6**	**4.8**
Chamba	1.9	5.4	1.7	5.2	1.5	4.7	2.7	6.2	1.6	5.1
Hamirpur	1.7	5.0	1.9	5.1	1.6	4.9	2.2	5.7	1.4	4.5
Kangra	1.8	5.2	1.8	5.1	1.5	4.8	2.3	5.8	1.5	4.8
Kullu	1.8	4.8	1.8	5.2	1.4	4.3	2.2	5.0	1.6	4.9
Mandi	1.7	4.8	2.0	5.3	1.5	4.6	2.2	5.0	1.4	4.4
Data Source: CORDEX South Asia RCM: Multi-Model Ensemble Mean										

Table 11 *Change in Precipitation (%) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 4.5 Scenario)*

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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	**5.6**	**11.8**	**-13.8**	**-23.8**	**-4.0**	**-15.2**	**15.4**	**23.3**	**-5.2**	**17.8**
Chamba	4.3	9.4	-14.6	-25.7	-3.2	-15.6	16.7	23.4	-6.7	16.7
Hamirpur	7.1	14.9	-21.5	-31.5	-12.0	-22.9	14.1	20.9	-10.1	18.5
Kangra	6.4	13.5	-17.3	-31.0	-7.8	-21.9	16.3	24.8	-8.1	17.9
Kullu	4.1	8.8	-9.5	-17.5	-3.4	-13.8	16.2	25.0	-1.4	18.5
Mandi	6.0	15.3	-19.9	-27.7	-12.6	-20.5	12.2	21.7	-4.0	22.4
Data Source: CORDEX South Asia RCM: Multi-Model Ensemble Mean										

Table 12 *Change in Precipitation (%) w.r.t. BL (1981–2010) as Simulated by South Asia CORDEX for Pong Dam Lake Basin (IPCC AR5 RCP 8.5 Scenario)*

	Annual		January, February (Winter)		March, April, May (Pre-Monsoon)		June, July, August, September (Monsoon)		October, November, December (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										

Table 13 List of Climate Extremes Indices

Index	Descriptive Name	Definition	Units
Temperature extremes indices: TX is the daily maximum temperature; TN is the daily minimum temperature			
Absolute indices			
TXx	Maximum of daytime temperature	Monthly maximum value of daily maximum temperature	°C
TNx	Maximum of night-time temperature	Monthly maximum value of daily minimum temperature	°C
TXn	Minimum of daytime temperature	Monthly minimum value of daily maximum temperature	°C
TNn	Minimum of night-time temperature	Monthly minimum value of daily minimum temperature	°C
Percentile indices			
TN10p	Cool nights	Annual percentage of days where minimum temperature is less than the 10th percentile of the base period	%
TX10p	Cool days	Annual percentage of days where maximum temperature is less than the 10th percentile of the base period	%
TN90p	Warm nights	Annual percentage of days where minimum temperature is more than the 90th percentile of the base period	%
TX90p	Warm days	Annual percentage of days where maximum temperature is more than the 90th percentile of the base period	%
Duration indices			
WSDI	Warm spell	Annual count of days with at least six consecutive days, when maximum temperature is greater than the threshold (calculated as 90th percentile of base period maximum temperature)	Days
CSDI	Cold spell	Annual count of days with at least six consecutive days, when minimum temperature is less than the threshold (calculated as 10th percentile of base period minimum temperature)	Days
Precipitation extremes indices: RR is the daily rainfall rate. A wet day is defined as RR ≥ 1mm and a dry day as RR<1mm. All indices are calculated annually from January to December.			
Absolute indices			
RX1day	1-day maximum precipitation	Highest precipitation amount in 1-day period	mm
RX5day	5-day maximum precipitation	Highest precipitation amount in 5-day period	mm
Percentile indices			
R95p	Very wet day precipitation	Annual total precipitation when precipitation is greater than the threshold (calculated as 95th percentile of base period precipitation)	mm

Index	Descriptive Name	Definition	Units
Precipitation extremes indices: RR is the daily rainfall rate. A wet day is defined as RR ≥ 1mm and a dry day as RR<1mm. All indices are calculated annually from January to December.			
R99p	Extremely wet day precipitation	Annual total precipitation when precipitation is greater than the threshold (calculated as 99th percentile of base period precipitation)	mm
Duration indices			
CDD	Consecutive dry days	Maximum length of dry spell (consecutive days with precipitation less than 1mm)	days
CWD	Consecutive wet days	Maximum number of consecutive wet days	days
		Threshold indices	
R10mm	Heavy precipitation days	Annual count of days when precipitation is greater than 10 mm	days
R20mm	Very heavy precipitation days	Annual count of days when precipitation is greater than 20 mm	days
Other indices			
PRCP-TOT	Wet-day precipitation	Annual total precipitation from wet days	mm
SDII	Simple daily intensity index	Average precipitation on wet days	mm/day

APPENDIX II

Important parameters of Ecological Health Index (EHI) and Ecological Quality Index (EQI)

Ecological Health Index

- High flow
- Very high flow
- Low flows
- Very low flow
- Water velocity
- Seasonality flow shift
- Persistently high flow
- Persistently low flow
- Flood flow interval

Ecological Quality Index

- Turbidity
- BOD
- COD
- pH
- Nitrogen
- Phosphorus
- Faecal bacteria
- TDS
- Total hardness
- Calcium hardness
- Water temperature
- Conductivity
- Chloride
- Fluoride
- Dissolved oxygen

APPENDIX III

Status and trends in components, processes and services of Pong Dam Lake

Wetland ‘ecological character’ can be defined as ‘the combination of the ecosystem components, processes and benefits/services that characterize the wetland at a given point in time’.

Ecological Character Element	Parameters	Status	Trend	Data Source
		Extent		
Wetland area	Annual inundation regime	Fluctuation from 65 km² to 260 km² (within a year). Inundation area depends on inflow coming to wetland. Depth of inundation can be affected by sedimentation.	In 2019 & 2020 it has increased due to increase in inflow from upstream and 1-day maximum rainfall. ⇧	United States Geological Survey (USGS) Earth Explorer :Landsat -8, Sentinel satellite images (2010 to 2020)
Habitats within wetland complex	Wetland habitats classification	Habitats can be assumed to have improved since migratory and resident birds have increased over the years (till 2020)	Increased ⇧	Various literature sources and wildlife status
		Catchment/spring-shed(climate, land use)		
Climate	Rainfall, temperature, extreme events		**Weather** ⇧ Precipitation Maximum temperature Minimum temperature **Extreme Events** ⇩ Cool nights Cool days Cold spell **Extreme Events** Max of daytime temp Max of night-time temp	CORDEX South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune Multi-Model Ensemble of three RCMs –CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009 Baseline

Ecological Character Element	Parameters	Status	Trend		Data Source
Catchment/spring-shed(climate, land use)					
			Min of daytime temp Min of night-time temp Warm days Warm nights Warm spell 1-day max precipitation 5-day max precipitation Consecutive dry days Consecutive wet days		(1981–2010), Mid-Century (2021–2050), End-Century (2071–2100)
Land use and land cover in the catchment	Land use & land cover change	There is an increase in agriculture and built-up area. However, there has been reduction in forest and barren land. Such land use/land cover changes can impact the temperature and sediment load in the wetland, which in turn can change/alter the habitat behaviour of the wetland.	**Decadal Change in Land Use (2010 to 2020)** Agriculture (17%) Built-up area (65%) Forest (8%) Barren land (16%)	↑ ↓	UGSC Earth Explorer :Landsat-8 satellite images Year 2010 Year 2020
Hydraulic structures/soil & water conservation measures in the catchment	Location, number of structures, type, length of drainage affected	Two major interventions and diversion projects in the catchment (Pong and Pandoh). Small weir/micro hydro projects are also in the catchment.	Latest data on small structures constructed in the catchment need to be updated and rules need to be established		National Register of Large Dams NRLD & WRIS 2018 data
Sedimentation	Rate, quality, sources	**Sediment Rate** **Remote Sensing** 24.62 Mm3/year (2008–2009) 25.79 Mm3/year (2015–2016) **SWAT Hydrological Model** 23.14 Mm3/year (2015–2016) **Field Data (BBMB Reports)** 24.54 Mm3/year (2012–2015	Sedimentation rate is increasing	↑	UGSC Earth Explorer: Landsat-8 satellite images (Analysis for years 2008–2009 and 2015–2016) SWAT model BBMB survey

Ecological Character Element	Parameters	Status	Trend	Data Source
		Hydrology		
Water sources	Freshwater inflows from streams, rainfall, snowmelt, groundwater	This is a dynamic, continuous and natural process, which is handled by the hydrological model at daily time step		SWAT Model
Inflows into the wetland	Perennial/non-perennial streams joining the wetland (contributing system)	Four (Main Beas, Dehar Khad, Gaj Khad, Baner Khad)		
Outflow	Outflow reservoir	It is a regulated flow by BBMB		SWAT model
Water balance	Inflows, outflows, evaporation			SWAT Model
Storage capacity	Annual change in reservoir level or water availability	Two major interventions and diversion projects in the catchment (Pong and Pandoh). Small weir/ micro hydro projects are also in the catchment.	Latest data and small structures constructed in the catchment need to be updated	NRLD & WRIS 2018 data
Water depth profile	Bathymetric profile	Not done	NA	NA
Water quality (inflows and wetland)	Salinity, dissolved oxygen, TDS, coliform, pH, nutrients, pollutants, BOD, COD, turbidity	All parameters are within permissible range	All parameters are within permissible range	CIFRI
Surface and groundwater connectivity	Hydrological model parameters	This is a dynamic and natural process, which is handled by the hydrological model at a daily time step		SWAT model
Nutrient status of wetland and nutrient flux	Phosphate, organic matter, Nitrate, Nitrite	From agriculture, urban waste	All parameters are within permissible range	CIFRI
Water abstraction	Diversion at Pandoh	Diversion to Sutlej from Pandoh dam	Constant	BBMB reports

Ecological Character Element	Parameters	Status	Trend		Data Source
Hydrology					
Sources of pollution	Turbidity and nutrient	From agriculture, urban and barren land	Increasing over the years		Satellite images and water quality data from BBMB report, CIFRI field data

APPENDIX IV

Analysis of risks of change in ecological character

Major threats to ecological character	Cause of threat	Likely impact on ecosystem services	Degree of impact	Current management practice / recommendations	Additional comments / information required
Climate change impact – spatial and temporal	CO_2 emission	Frequent Floods Influx of debris Warm nights Warm day Unequal distribution of rainfall	Moderate	Afforestation, alternative livelihoods options, desilting of reservoi, installation of silt trap	Afforestation needs to be done in the catchment to counter the temperature increase. Silt trap should be installed at mouth of the river where it flows into the wetland. Location can slightly vary depending on local knowledge and available space. Alternative livelihood options like eco-tourism or fishery or beekeeping etc. should be promoted. Additional local knowledge is required to understand the local demand and mindset of the people and to link these with present schemes. Early warning & Flood Forecasting system shall help in mitigating the sudden flood. Need information from BBMB for upstream releases and INRM can help in generating FFEWS system.
Turbidity	Sediments	When sunlight is blocked from penetrating through the water, high concentrations of particulate matter will modify light penetration,	Low	Afforestation, desilting of reservoir, installation of silt trap at mouth of wetland, providing buffer	Buffer Strips shall be placed at the periphery of the wetland, exact location and type of buffer strips need joint working with the wetland authority / site manager / wildlife authority / local people. Silt trap should be installed at mouth of the

Major threats to ecological character	Cause of threat	Likely impact on ecosystem services	Degree of impact	Current management practice / recommendations	Additional comments / information required
		causing shallow lakes and bays to fill in faster and smother benthic habitats. This impacts both underwater organisms and their eggs.		strips near wetland to arrest the excessive sediment	river where it flows into the wetland. Location can slightly vary depending on local knowledge and available space.
Nutrients	Use of fertilizer and pesticides in the catchment	Excess nutrients over-stimulate the growth of aquatic plants and algae, which clog our waterways and block light to deeper waters while the organisms are alive; when the organisms die, they use up dissolved oxygen as they decompose, causing oxygen-poor waters that support only diminished amounts of marine life. Pesticides can contaminate soil, water, turf, and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to a host of other organisms including birds, fish, beneficial insects, and non-target plants.	Low	Restricted use of pesticide and fertilizer, providing buffer strips near wetland to arrest the excessive sediment and nutrient, alternative livelihood options, zonation within wetland.	Buffer Strips shall be placed at the periphery of the wetland. Wherever cultivation is done near or in wetland buffer zone, there these buffer strips shall be placed. Exact location and type of buffer strips need joint working with the wetland authority / site manager / wildlife authority / local people. Usage of Pesticide and Fertilizer should be restricted in buffer zone of wetland. Pesticide and Fertilizer commonly used in the agricultural practices are used, in case these are not used, it should be discussed and altered. Alternative livelihood options like eco-tourism or fishery or beekeeping etc. should be promoted. Additional local knowledge is required to understand the local demand and mindset of the people and to link these with present schemes. Local knowledge is required to demarcate the wetland into zones.
Overlapping Interest	Human	Interference of human can impact the ecology / habitats of wetland.	Moderate	Dividing wetland into zones, with restrictions Creation and promotion of alternative livelihood option like eco-tourism, fishery, beekeeping, livestock, horticulture etc, protection of species	Alternative livelihood options like eco-tourism or fishery or beekeeping etc. should be promoted. Additional local knowledge is required to understand the local demand and mindset of the people and to link these with present schemes. Local knowledge is required to demarcate the wetland into zones, so that human interference / interaction is restricted / limited. It shall help in developing the area into eco-tourism spot and can generate additional revenue for the locals as well as authority to maintain and develop the area. Introduction of new species to wetland like some fish species depending on climate trends (increasing temperature). It shall help to maintain the ecological health of the wetland.

Registered Offices:

Bonn and Eschborn, Germany
Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Germany

Dag-Hammarskjold-Weg 1-5
65760 Eschborn, Germany

Email: info@giz.de

A2/18, Safdarjung Enclave
New Delhi-110029, India
Tel: +91 11 4949 5353
Fax: +91 11 4949 5391

Email: biodiv.india@giz.de