Hydrological Modelling of Narmada basin in Central India using Soil and Water Assessment Tool (SWAT)

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Presentation Outline

- Introduction
- Objectives
- Study area
- Methodology
- Climate change detection in historical time horizons
- Hydrologic Modelling
- Impact assessment for future time horizons

Introduction

Historical and Present time horizon:

Warming is Unequivocal and Unprecedented (IPCC).

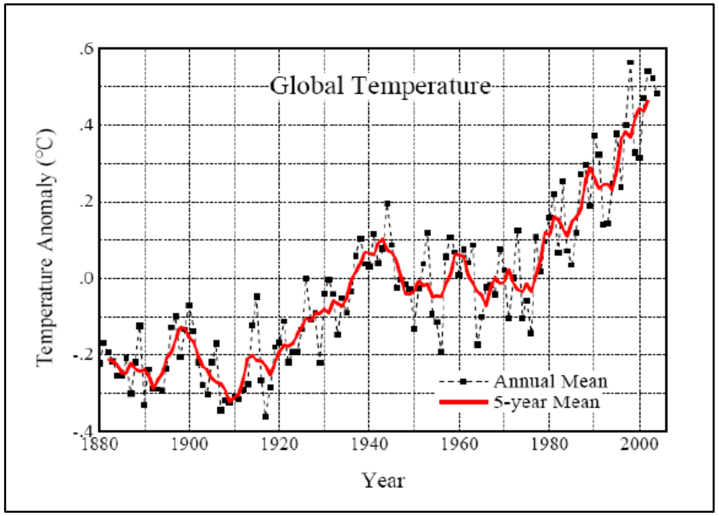
Water is one of the sectors going to be impacted.

Future time horizons:

Global temperature change *is likely to exceed 1.5°C* for the end of the 21^{st} century relative to 1850.

Expected to have significant impacts on the hydrological cycle.

- Application of climate change science remains a challenge.
  - Heavy analytical procedures
  - Limited attention to implementation
  - High level of uncertainty
  - Political dimensions



- Indian sub-continent: combination of
  - climate change
  - rapid population growth
  - land use change
  - adaptation mechanisms

- Hydrologic modelling can be a useful tool for scenario analysis for water resources planning

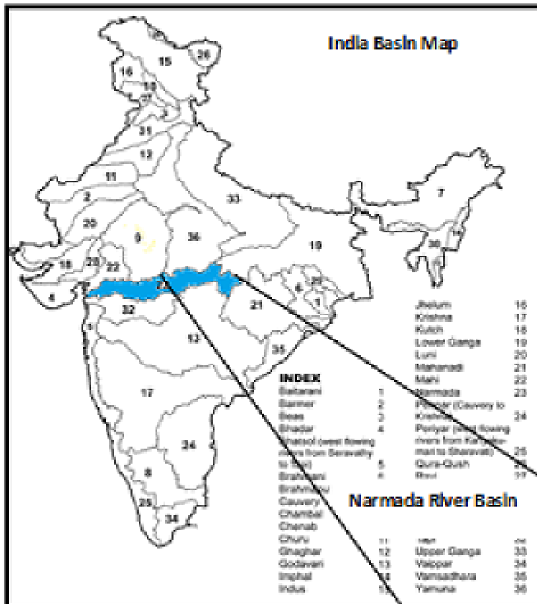
Objectives

- Identification of climate change signals in Narmada basin through statistical analysis of historical climate variables.

- Modelling the watershed hydrology in Narmada basin by a physically based large scale hydrologic model.

- Assessment of the impact of climate change using projected climate scenarios (AR5) with emphasis on future water availability including extreme events.

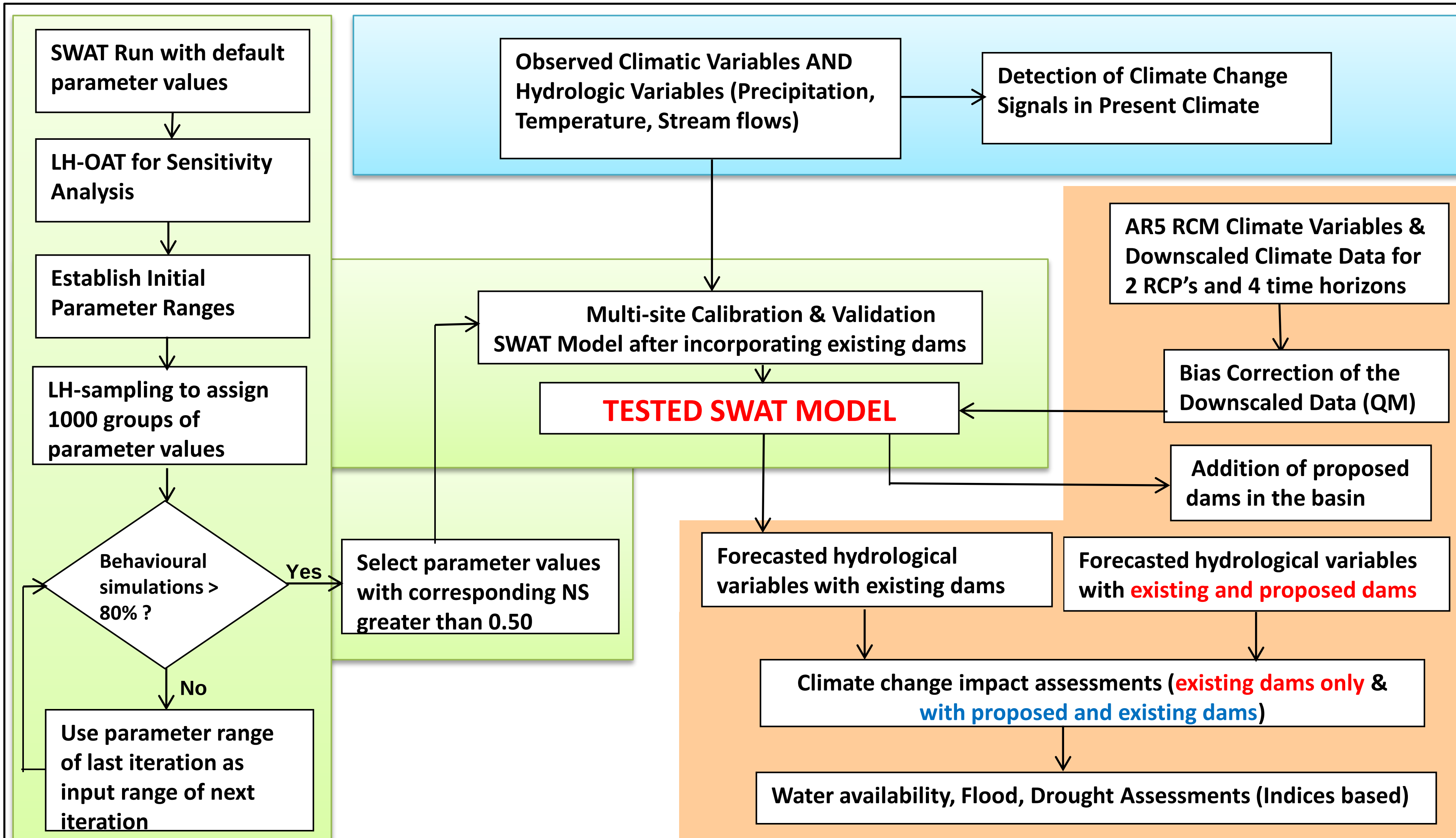
Study Area



- Catchment area: 98796 sq. km.
- Non-snowfed river basin
- Sustained by base flows
- West flowing river
- Lies in the States of MP, Gujarat,
- Maharashtra and Chhattisgarh
- Average annual rainfall: 1178 mm

- 30 major & 150 medium projects planned in Narmada basin.
- Sustainability of the existing and upcoming projects uncertain.
- Hydrological impact assessments are much more imperative now.
  - Non snow-fed perennial basin
  - Sustained only by base flow
  - Change in water balance components
- Predictions of hydrologic variables in future under climate change.
- Research gaps:
  - impact assessment in data scarce areas
  - Uncertainty issues,
  - Non-stationarity issues.

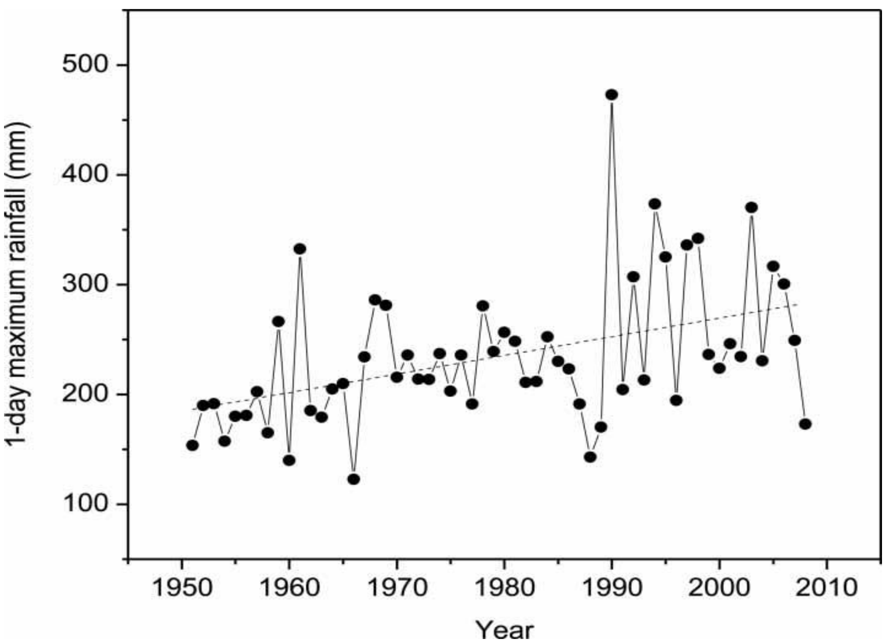
Methodology

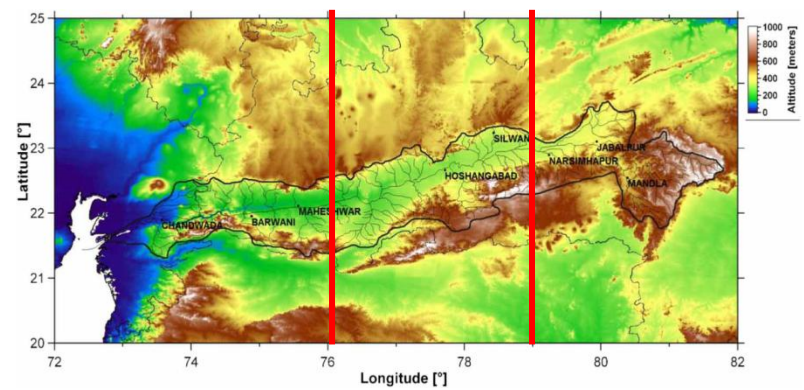


Extreme rainfall: Increased in recent times

- 1-day maximum P: Significant positive trend (z = 3.66)

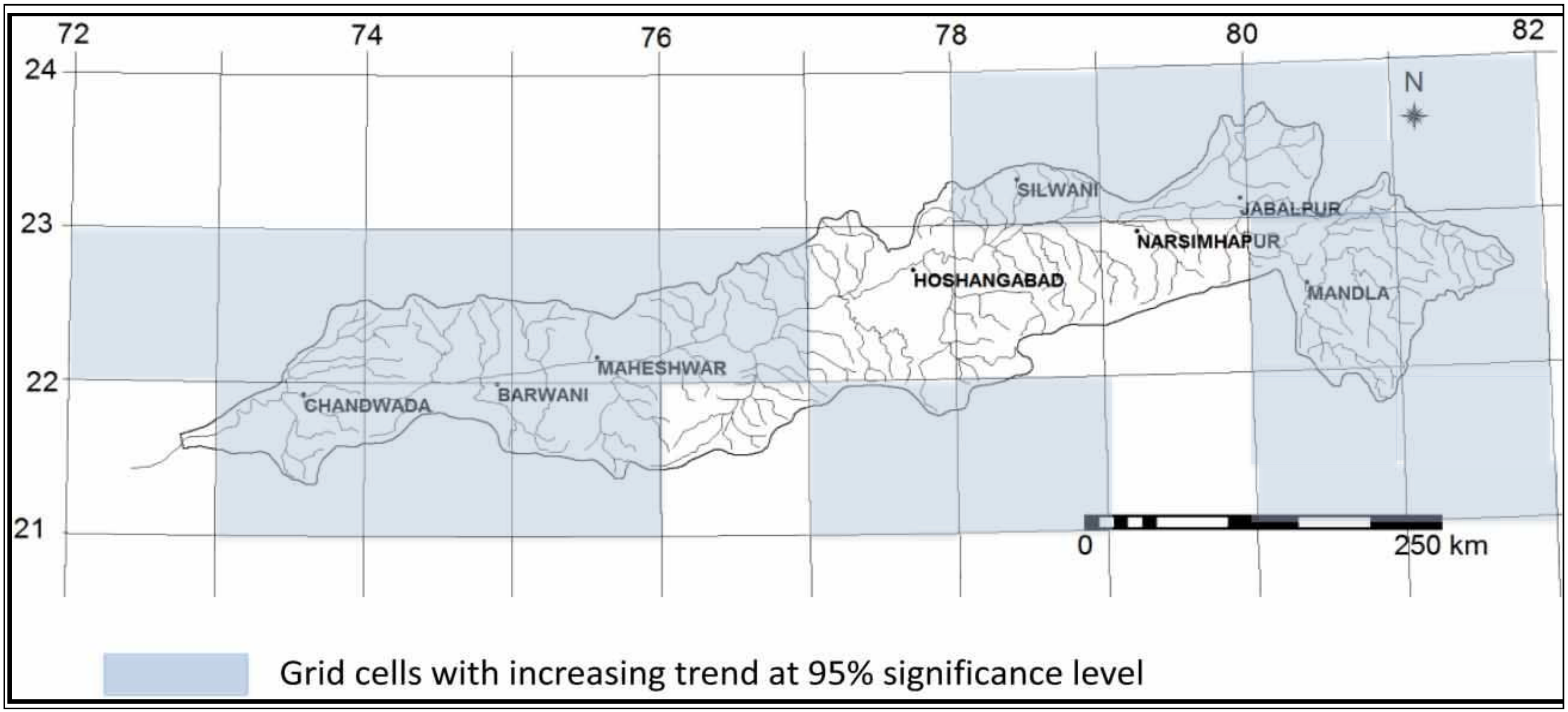
Particulars	1951-70	1989-08
1-day rainfall > 300 mm	1	9
1-day rainfall > 200 mm	8	17
Average 1-day maximum rainfall	203.9 mm	275.9 mm





Temporal variation of amount of 1-day maximum rainfall in the basin (MK test z statistic = 3.66).

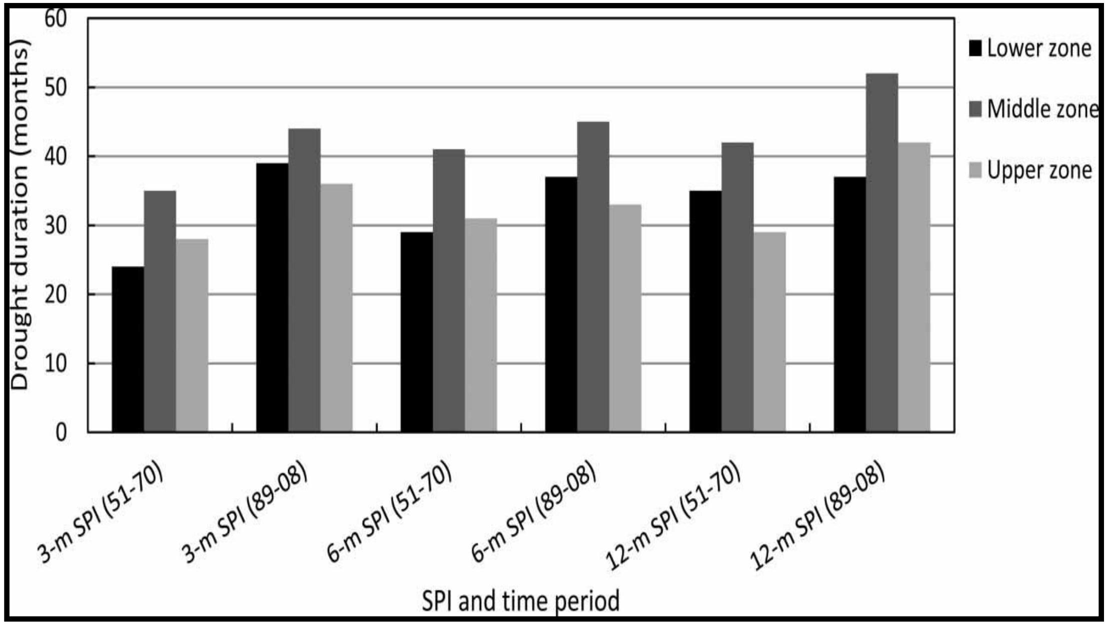
Frequency analysis: Increase in n-yr return period rainfall



Grid cells with significant increasing trends in 5-year return period rainfall

Droughts: Increased in recent times

- Drought frequency more pronounced in the middle zone.
- Increase of drought in upper zone a cause of concern.



SPI based drought duration for various zones

Extreme Temperatures: Increasing continuously

- 1-day maximum temperature : increasing @ 1.10°C/100 yr. *(more than global average rate).*
- 1-day minimum temperature: increasing @ 3.20°C/100 yr**.**

S. No.	Zones of basin	Mann-Kendall test statistic & inference	
		1969-88	1990-2009
1.	Upper zone	+1.72 (not significant)	+1.01 (not significant)
2.	Middle zone	+1.24 (not significant)	+1.29 (not significant)
3.	Lower zone	+2.31 (significant)	+2.11 (significant)

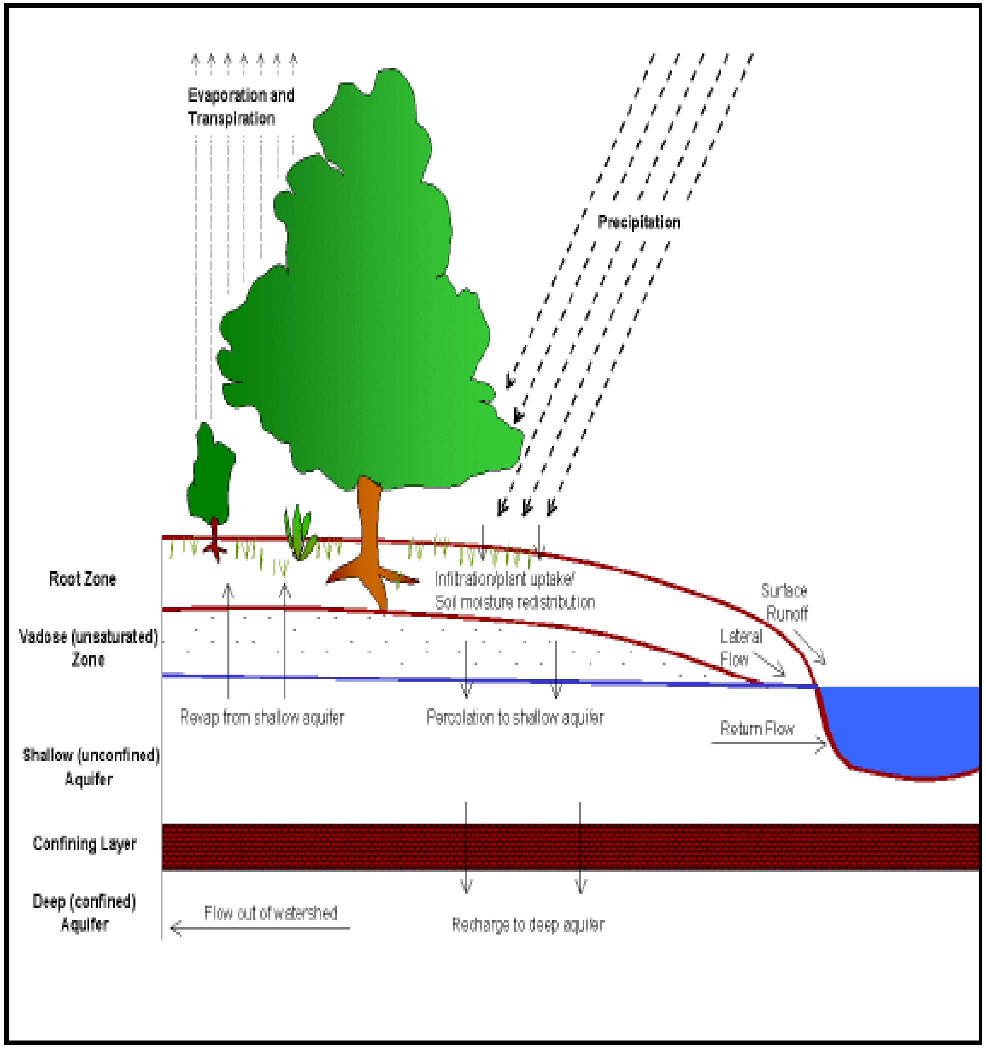
Hydrologic Modelling using SWAT

Features of SWAT

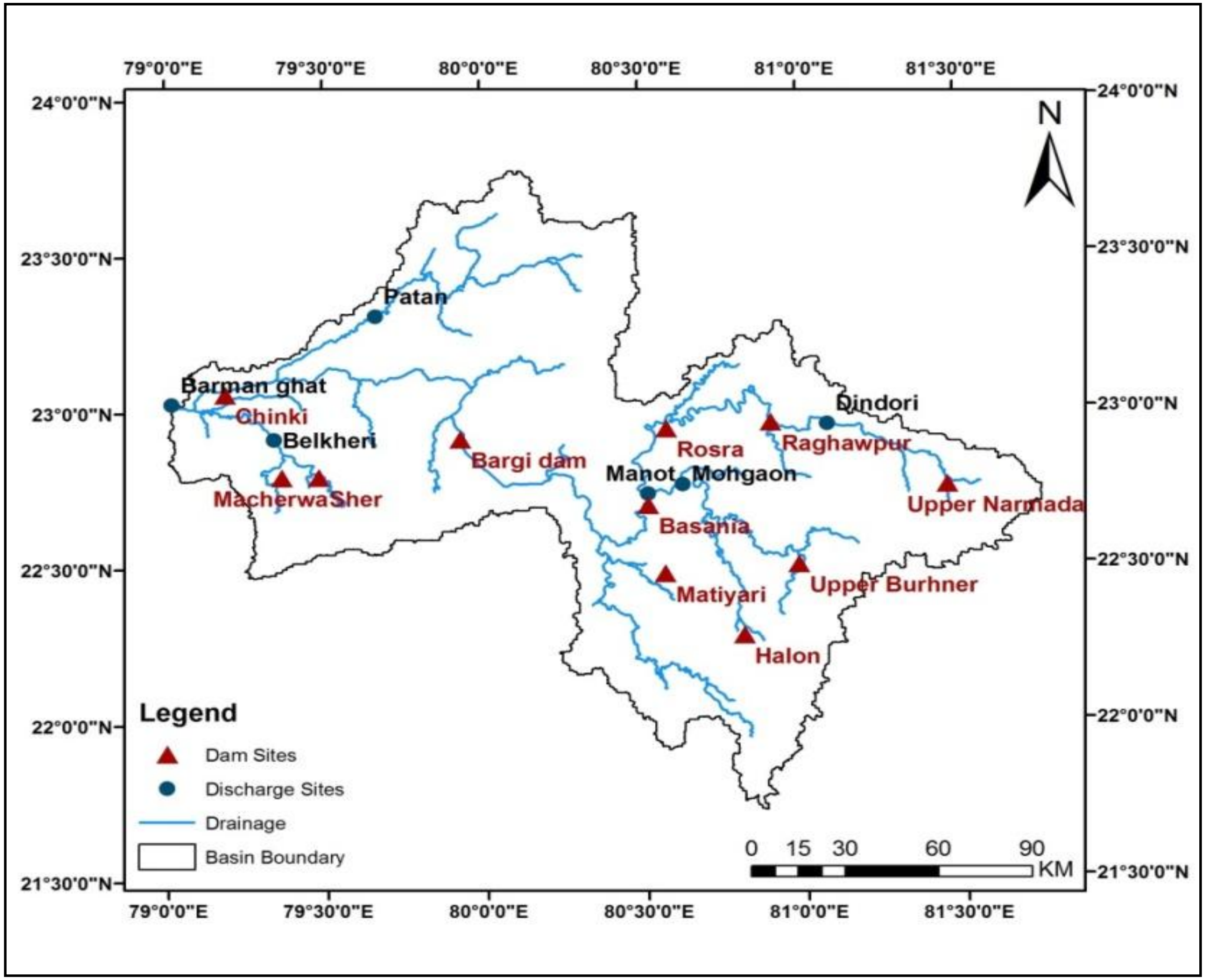
- Physically based distributed model
- Continuous time model
- Long term yield model
- Uses readily available data
- Can be used for long term impact studies

Processes Modelled

- Weather, Hydrology, Sedimentation
- Plant growth, Nutrient cycling
- Pesticide dynamics, Bacteria
- Management



SWAT setup for the Narmada up to Barmanghat



- SWAT model setup for the Narmada upto Barmanghat (26000 sq. km).
- One Major Multi-purpose Project (Bargi Dam) for irrigation, power generation, industrial and domestic use.
- 10 projects being planned in the catchment : Rosra, Basania, Halon, Upper Narmada, Upper Burhner, Raghavpur, Atariya, Machhrewa, Sher and Chinki.
- Virgin simulation of the model has been carried out before setting up of reservoirs.
- Default run of model Bargi Reservoir (properties and inflows).

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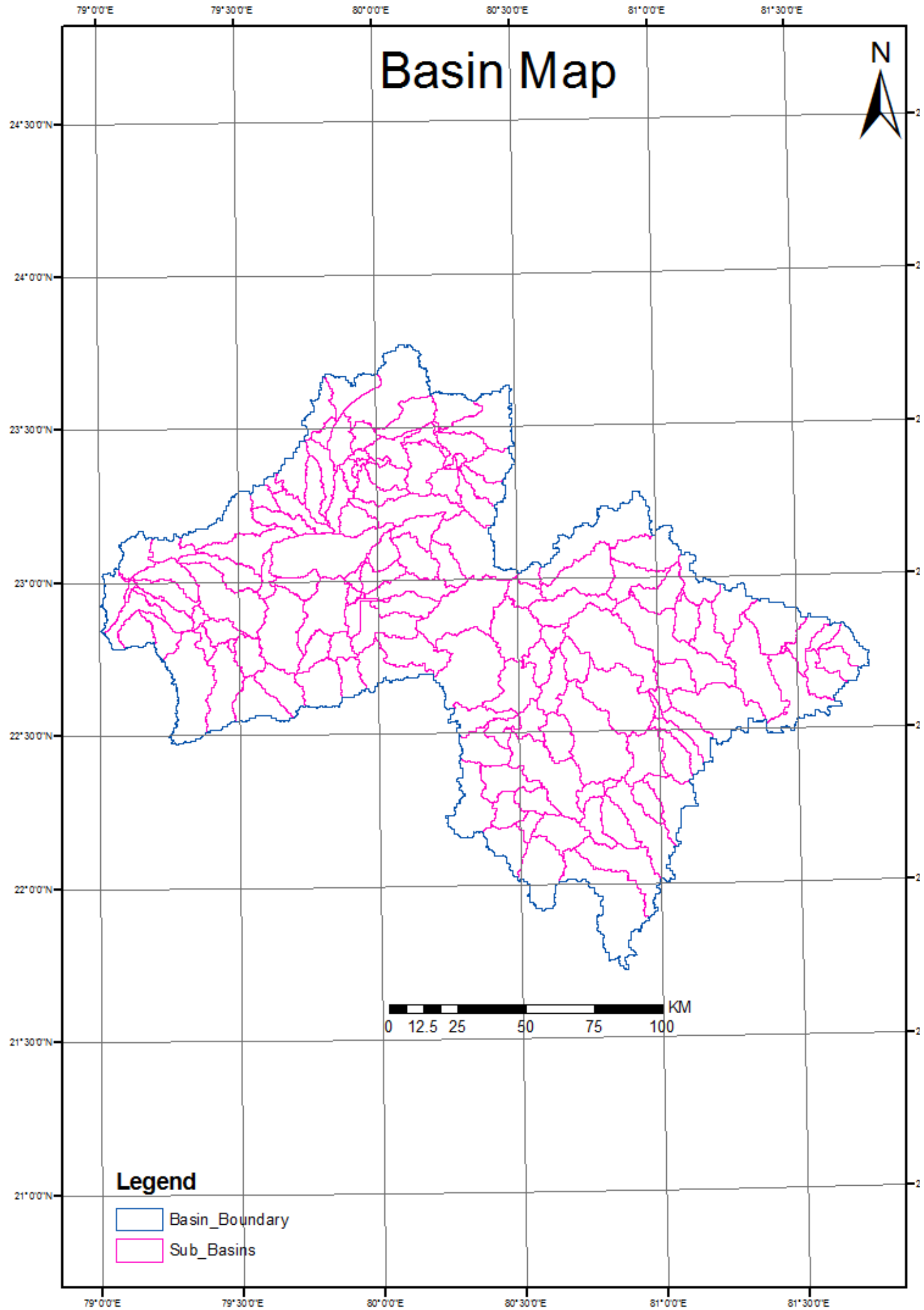
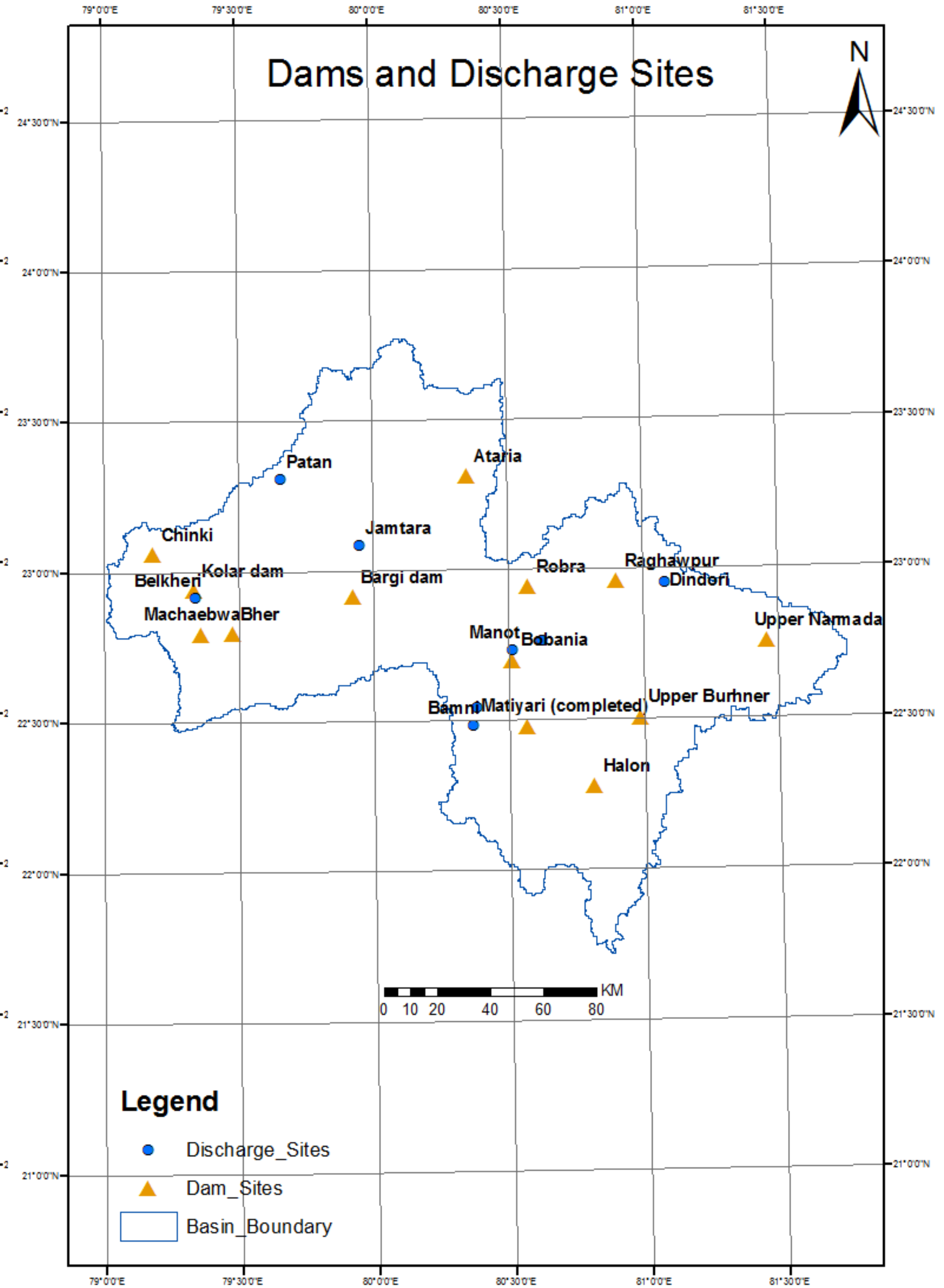
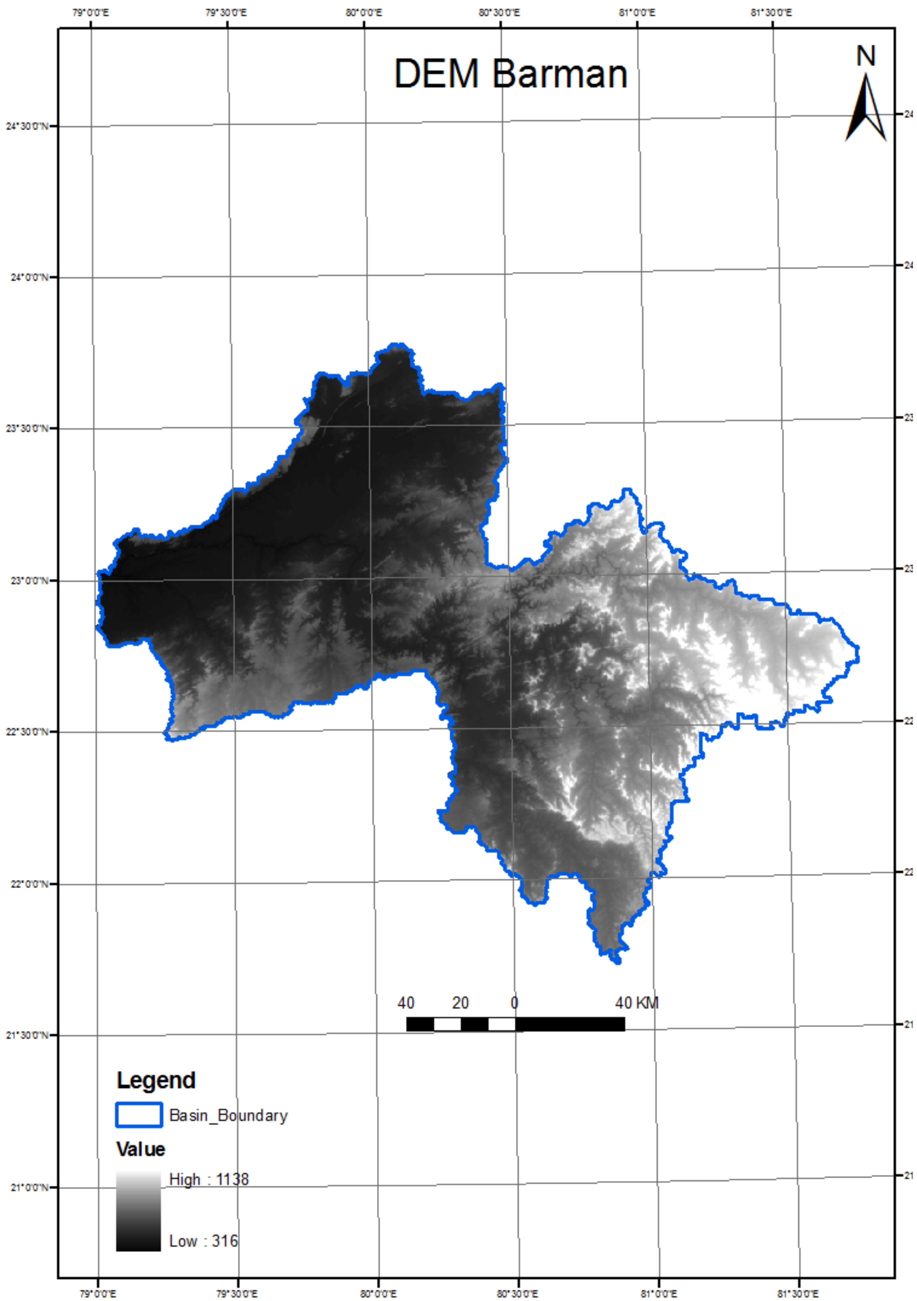
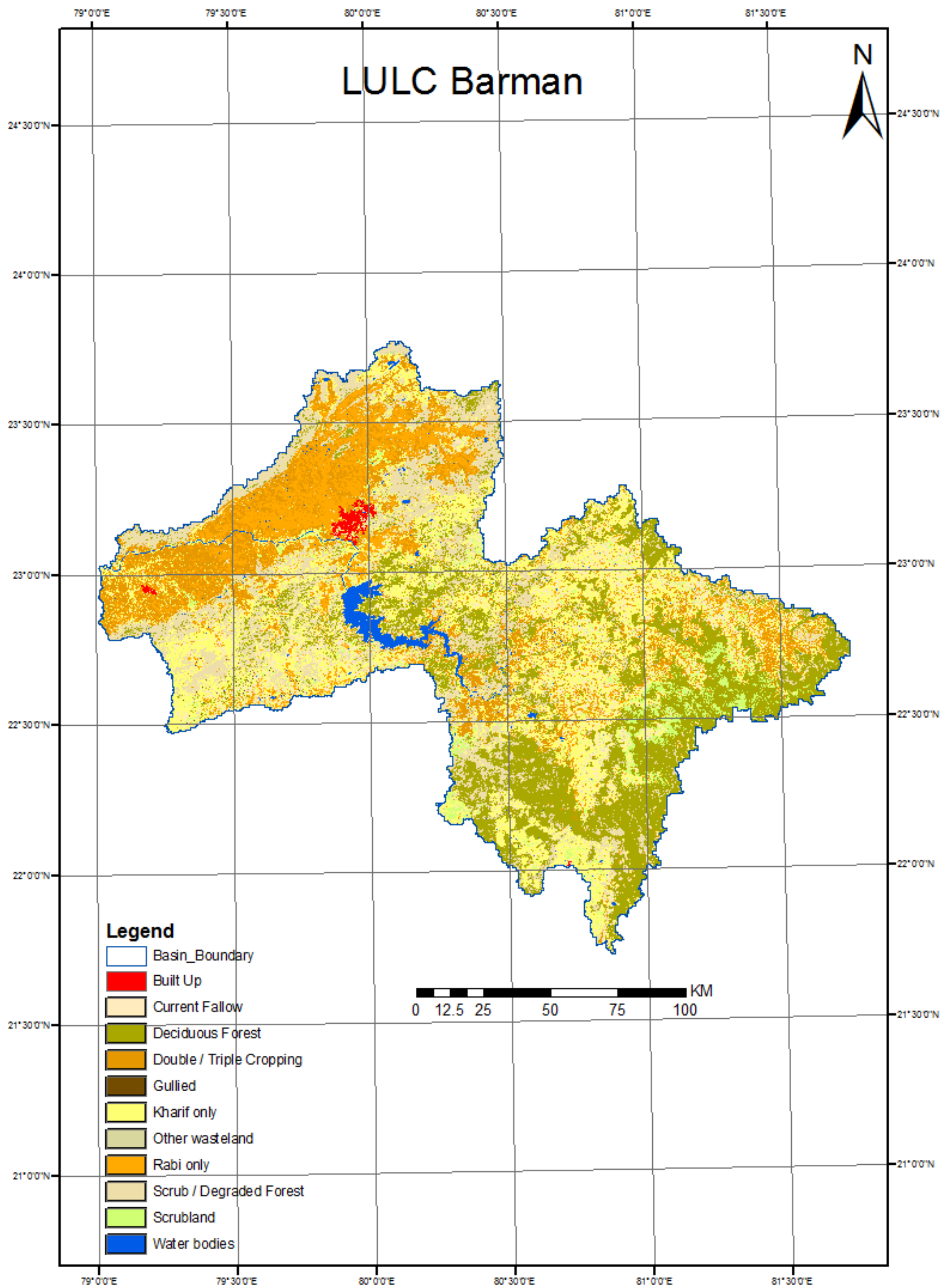
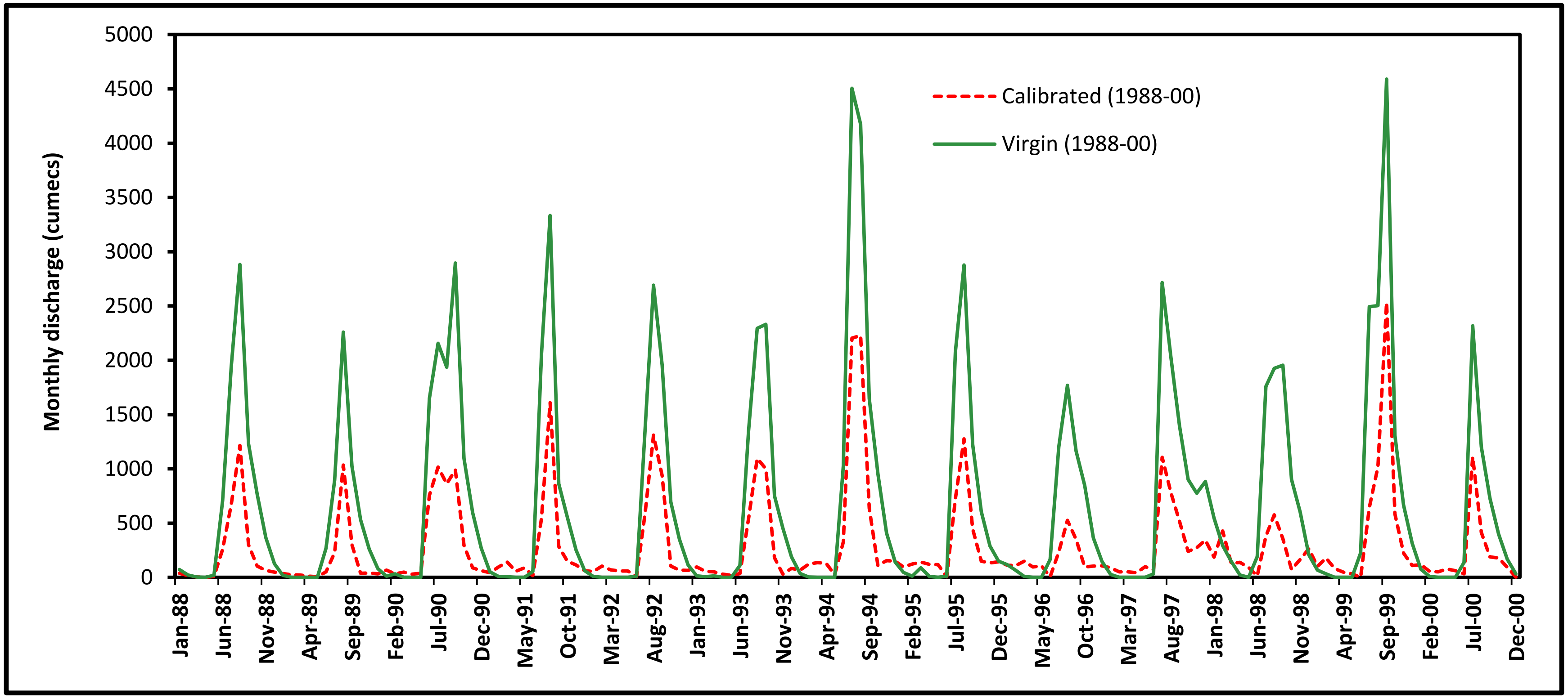

Basin Map
N
KM
0 12.5 25 50 75 100
Legend
Basin_Boundary
Sub_Basins


Dams and Discharge Sites
N
Patan
Ataria
Chinki
Jamtara
Kolar dam
Belkheri
Bargi dam
Robra
Raghawpur
Dindori
MachaebwaBher
Manot
Bobania
Upper Narmada
Bamni
Matiyari (completed)
Upper Burhner
Halon
KM
0 10 20 40 60 80
Legend
Discharge_Sites
Dam_Sites
Basin_Boundary


DEM Barman
N
40 20 0 40 KM
Legend
Basin_Boundary
Value
High : 1138
Low : 316


LULC Barman
N
Legend
Basin_Boundary
Built Up
Current Fallow
Deciduous Forest
Double / Triple Cropping
Gullied
Kharif only
Other wasteland
Rabi only
Scrub / Degraded Forest
Scrubland
Water bodies
KM
0 12.5 25 50 75 100

DEFAULT RUN: VIRGIN AND BARGI DAM



- Sources of irrigation allocated: based on the actual water use of reservoir water in command areas & groundwater in non-command areas.

SWAT Parameters for Stream flow simulation

1. Base flow recession coefficient: ALPHA_BF
2. GW Delay time : GW_DELAY
3. Revap coefficient : GW_REVAP
4. Soil evaporation coefficient : ESCO
5. Available Water Content : SOL_AWC
6. Saturated hydr. Conductivity : SOL_K
7. Manning's n : OV-N

7. Curve number : CN_f
8. Slope : SLOPE
9. Manning's n for channel : CH_N
10. Water depth (shallow aq.) :GWQMN
11. Slope length of main channel : CH_S
12. Snowfall temperature : SFTMP
13. Slope of sub-basin : SLSUBBSN
14. Surface lag : SURLAG

- One at a time (LH-OAT) Sensitivity Analysis has been performed for the parameters responsible for stream flow simulation.

Multi-site SWAT Calibration

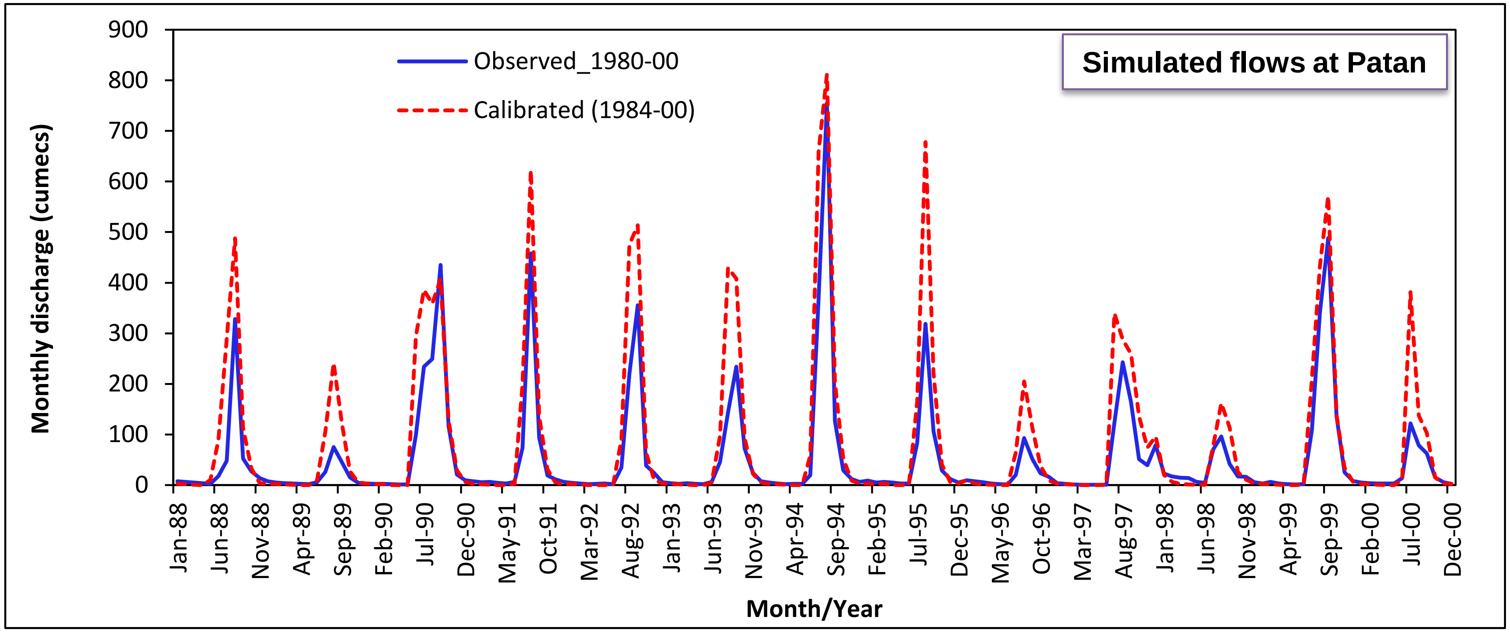
- Multi-site calibration of SWAT model using 6 gauging sites (Dindori, Mohgaon, Manot, Belkheri, Patan and Barmanghat)

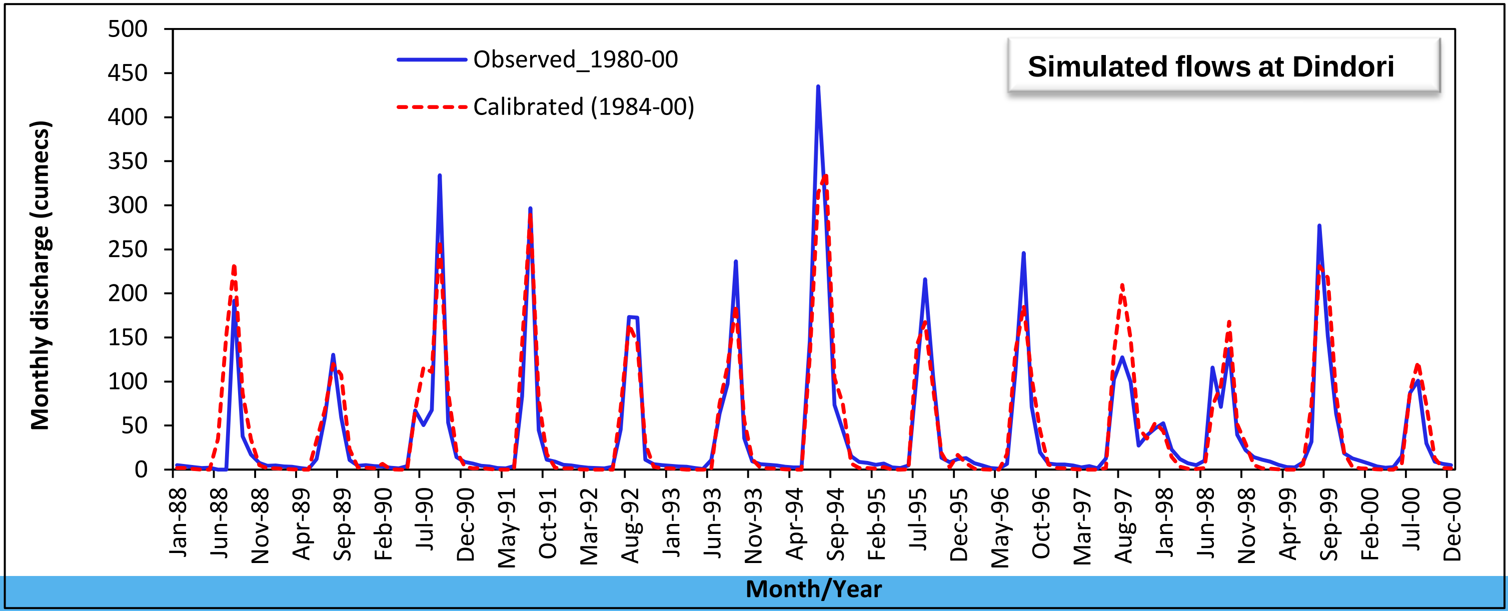
- Calibration: 1988-00, Validation: 2001-05

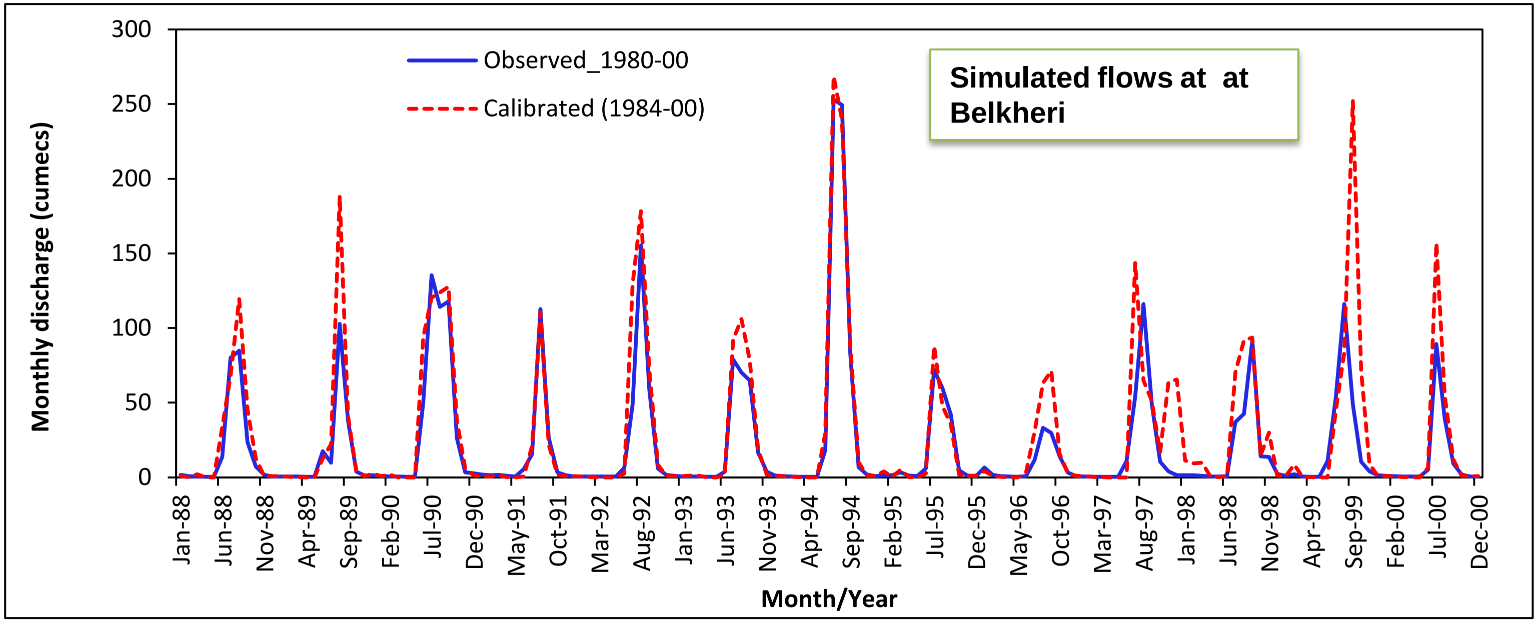
- Sensitivity Analysis has been performed for the parameters responsible for stream flow simulation.

- CN2, SOL_AWC, ESCO, GW_REVAP, ALPHA_BF and GW_DELAY.

Model calibration






Simulated flows at at Belkheri
Observed_1980-00
Calibrated (1984-00)
Monthly discharge (cumecs)
Month/Year
300
250
200
150
100
50
0
Jan-88
Jun-88
Nov-88
Apr-89
Sep-89
Feb-90
Jul-90
Dec-90
May-91
Oct-91
Mar-92
Aug-92
Jan-93
Jun-93
Nov-93
Apr-94
Sep-94
Feb-95
Jul-95
Dec-95
May-96
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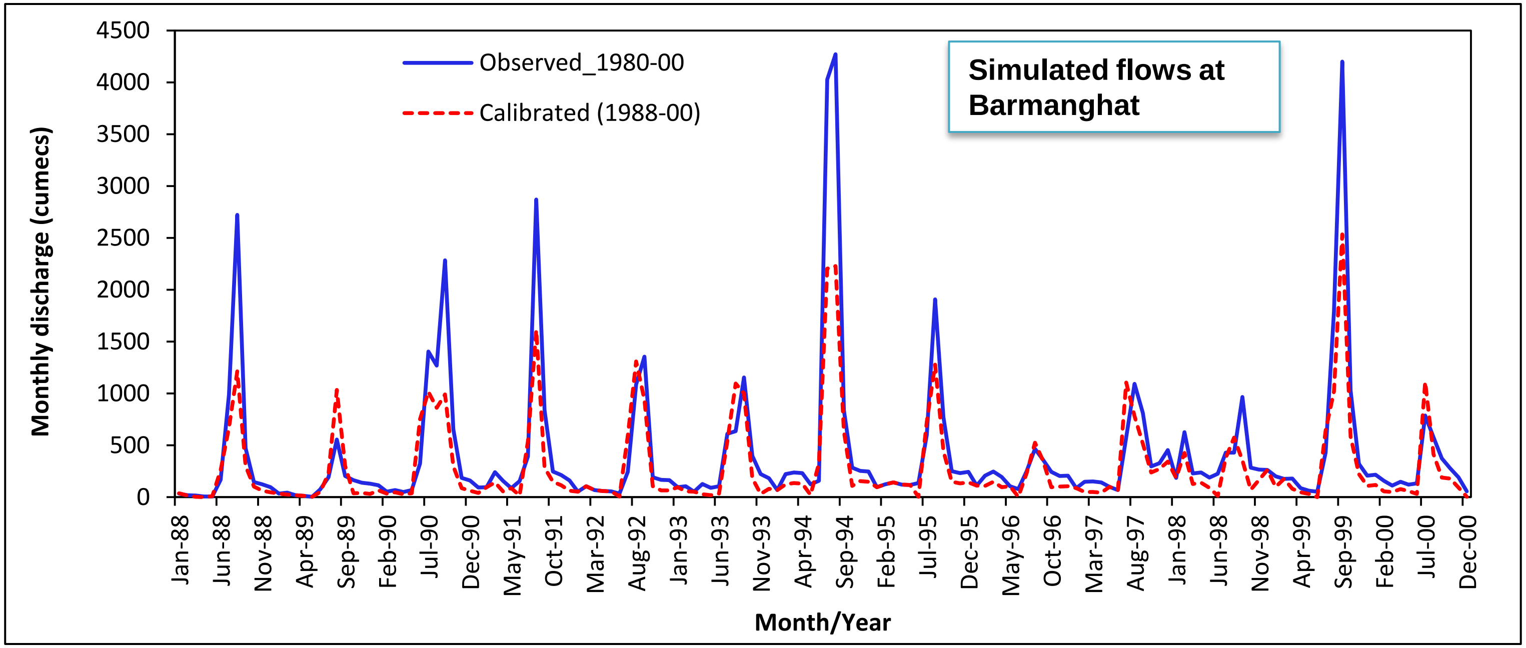
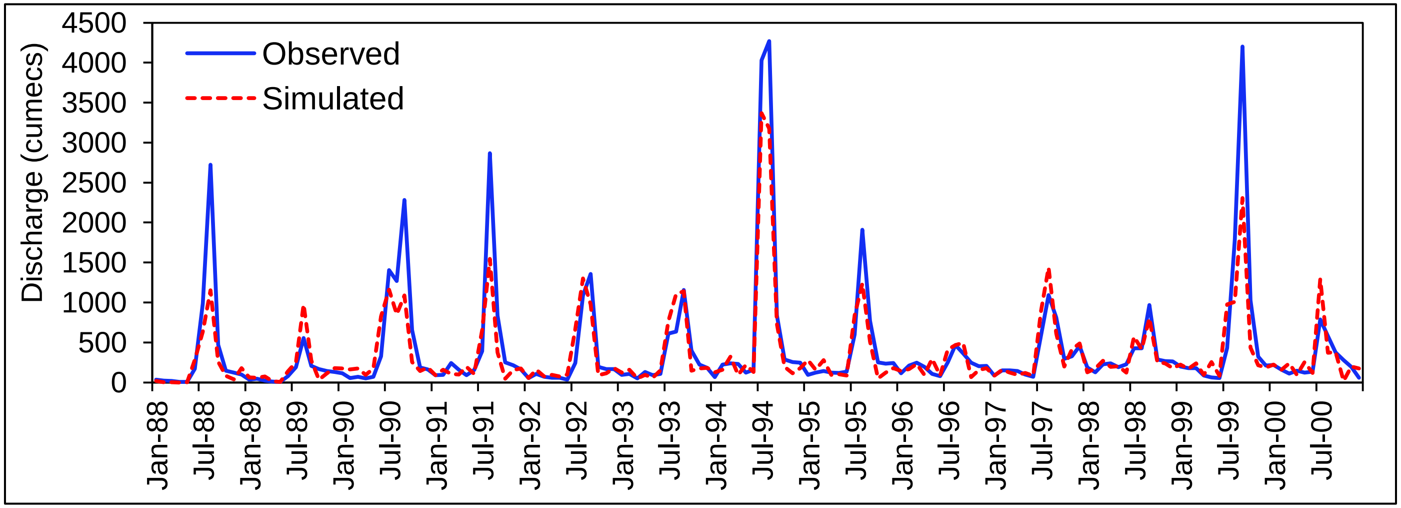
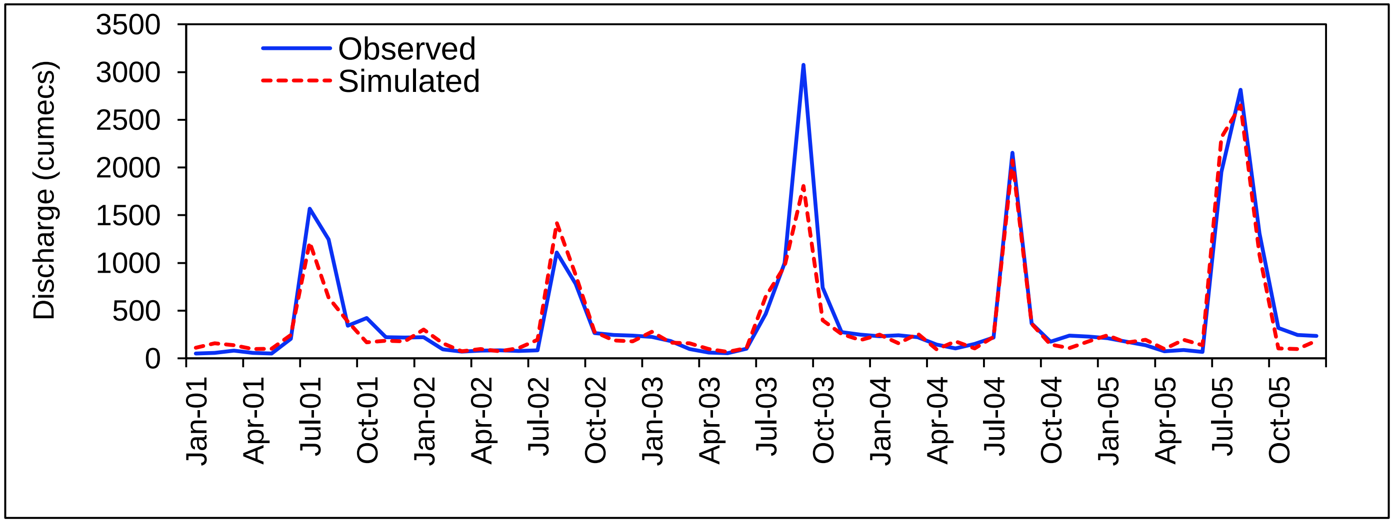
Sep-99
Feb-00
Jul-00
Dec-00


Simulated flows at Barmanghat
Observed_1980-00
Calibrated (1988-00)
Monthly discharge (cumecs)
Month/Year
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Jan-88
Jun-88
Nov-88
Apr-89
Sep-89
Feb-90
Jul-90
Dec-90
May-91
Oct-91
Mar-92
Aug-92
Jan-93
Jun-93
Nov-93
Apr-94
Sep-94
Feb-95
Jul-95
Dec-95
May-96
Oct-96
Mar-97
Aug-97
Jan-98
Jun-98
Nov-98
Apr-99
Sep-99
Feb-00
Jul-00
Dec-00

Observed & Simulated Hydrographs at Barmanghat





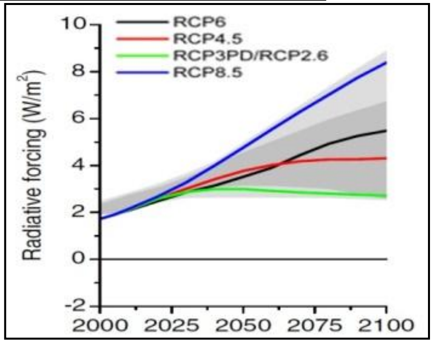
Model performance

S. No.	Name of the gauging site	Calibration			Validation		
		NSE	RSR	PBias	NSE	RSR	PBias
1.	Dindori	0.85	0.39	-7.48	0.85	0.32	-4.56
2.	Mohgaon	0.35	0.81	-37.60	0.90	0.28	-5.05
3.	Manot	0.95	0.23	-8.91	0.97	0.14	-1.57
4.	Patan	0.63	0.61	-50.45	0.68	0.51	-42.59
5.	Belkheri	0.90	0.32	-5.80	0.70	0.48	-18.61
6.	Barmanghat	0.79	0.46	13.93	0.79	0.28	8.33

Climate Change Impact Assessments

Global Climate Models (GCM)

Representation Concentration Pathways (RCPs)



Downscaling

Regional Climate Models (RCMs)

Bias Correction (Quantile mapping)

Calibrated and Validated SWAT Model

Multiple outputs of streamflow

Climate Models, RCPs and Extreme Events Indices

- 6 RCMs (0.50° x 0.50°)
  - CCSM4
  - CNRM-CM5
  - GFDL-CM3
  - ACCESS1.0
  - MPI-ESM-L
  - NOR-ESM-M
- 4 time-horizons
  - 1970-05 (historical)
  - 2006-40 (near term)
  - 2041-70 (mid term)
  - 2071-99 (end term)
- 2 RCP Scenarios
  - RCP4.5
  - RCP8.5

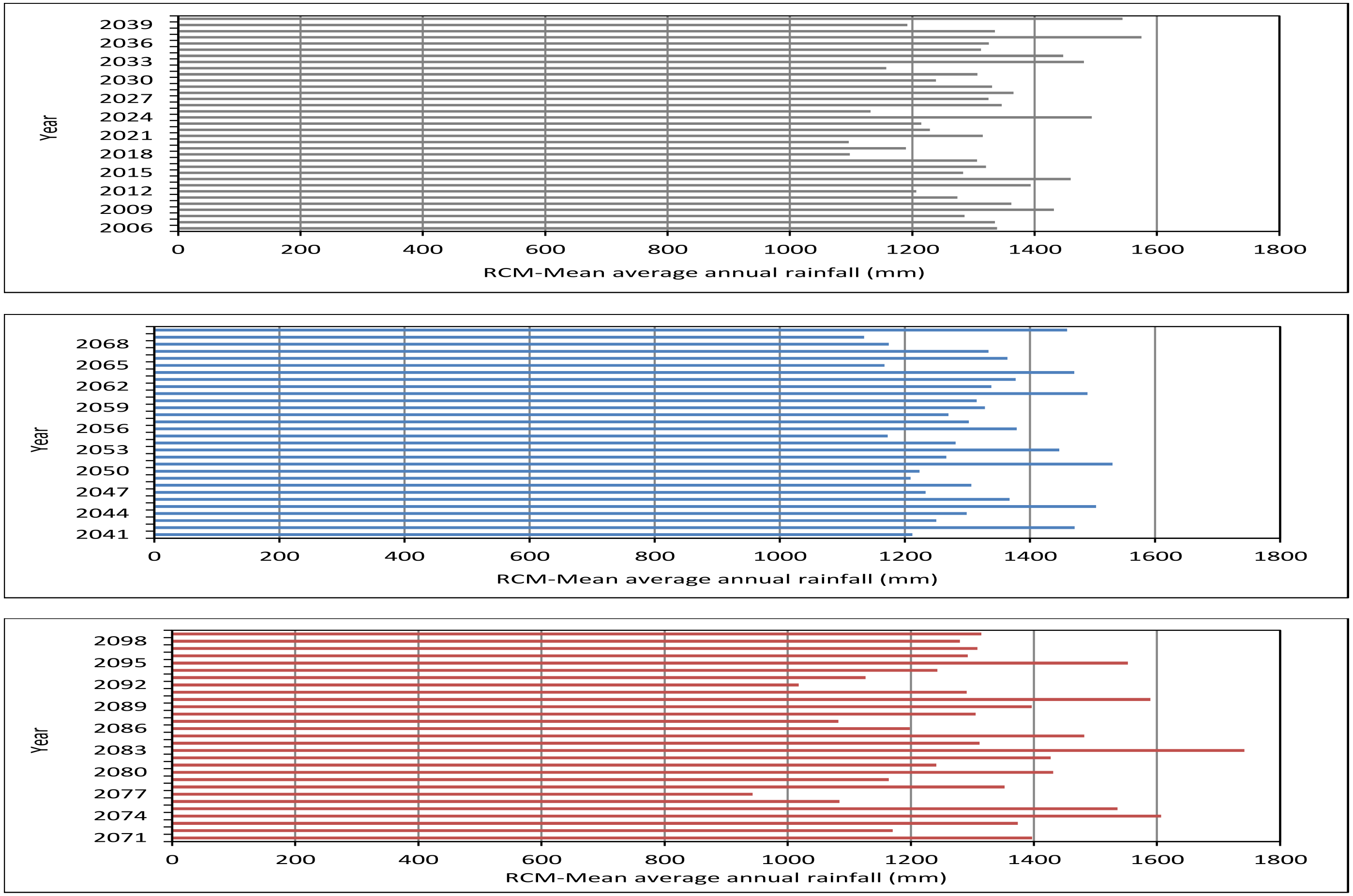
S.	Index	Rainfall range
1.	Wet day	> 2.50 mm
2.	Heavy rainfall day	100 mm - 200 mm
3.	Very heavy rainfall day	> 200 mm

Sl. #	Index	Range
1.	Extremely hot days	MaxT > 45°C
2.	Summer days	MaxT > 40°C
3.	Warmer Days	MaxT > 35°C
4.	Summer nights	MinT > 25°C

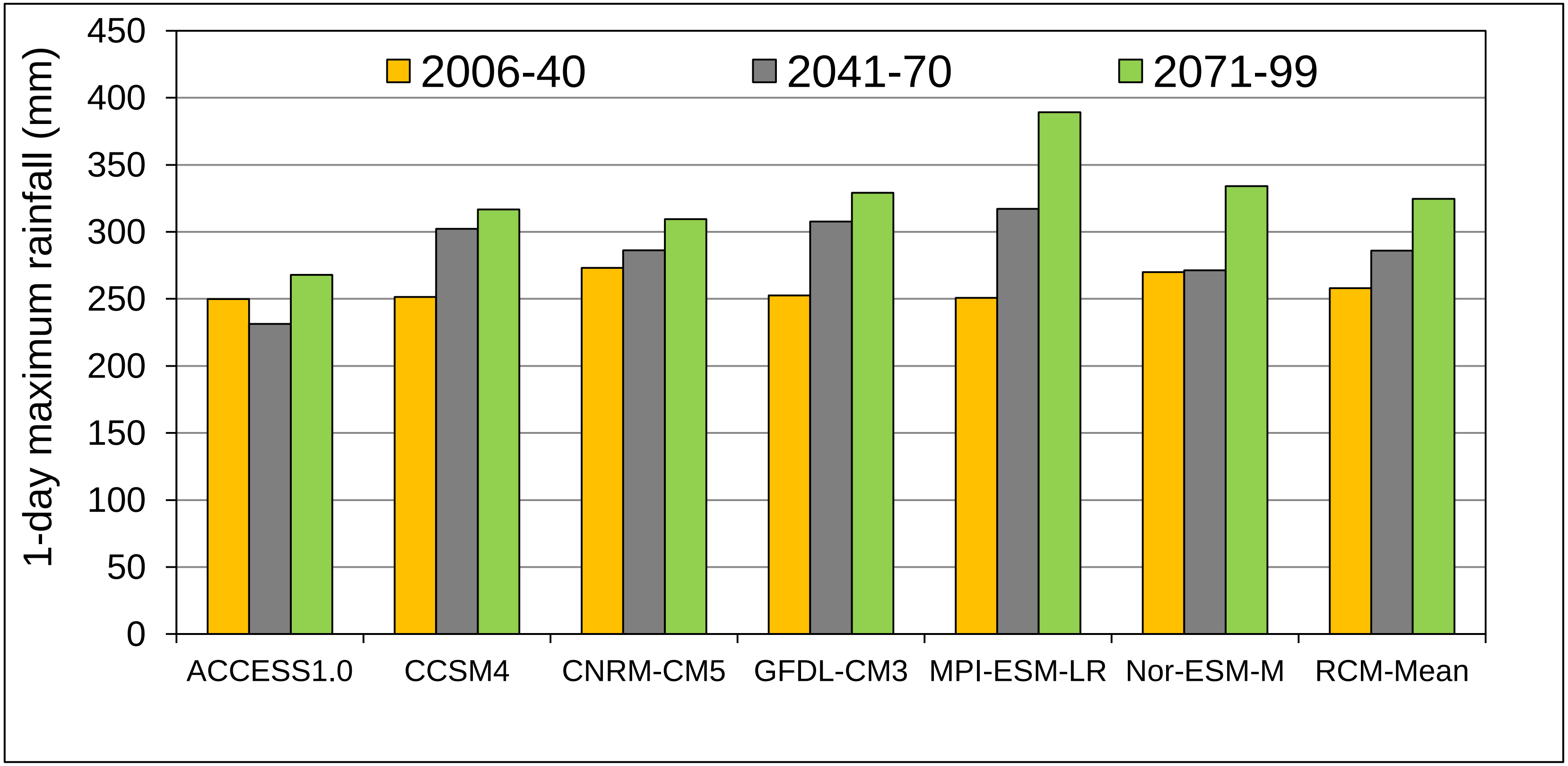
Source: European Climate Assessment & Dataset (ECA&D)

Scenario Analysis: Higher rainfall variability

RCM mean average annual rainfall under RCP4.5



Future scenario : Higher extreme rainfall events



Future 1-day maximum rainfall

Future scenario: Higher extreme temperatures

Extremely hot days

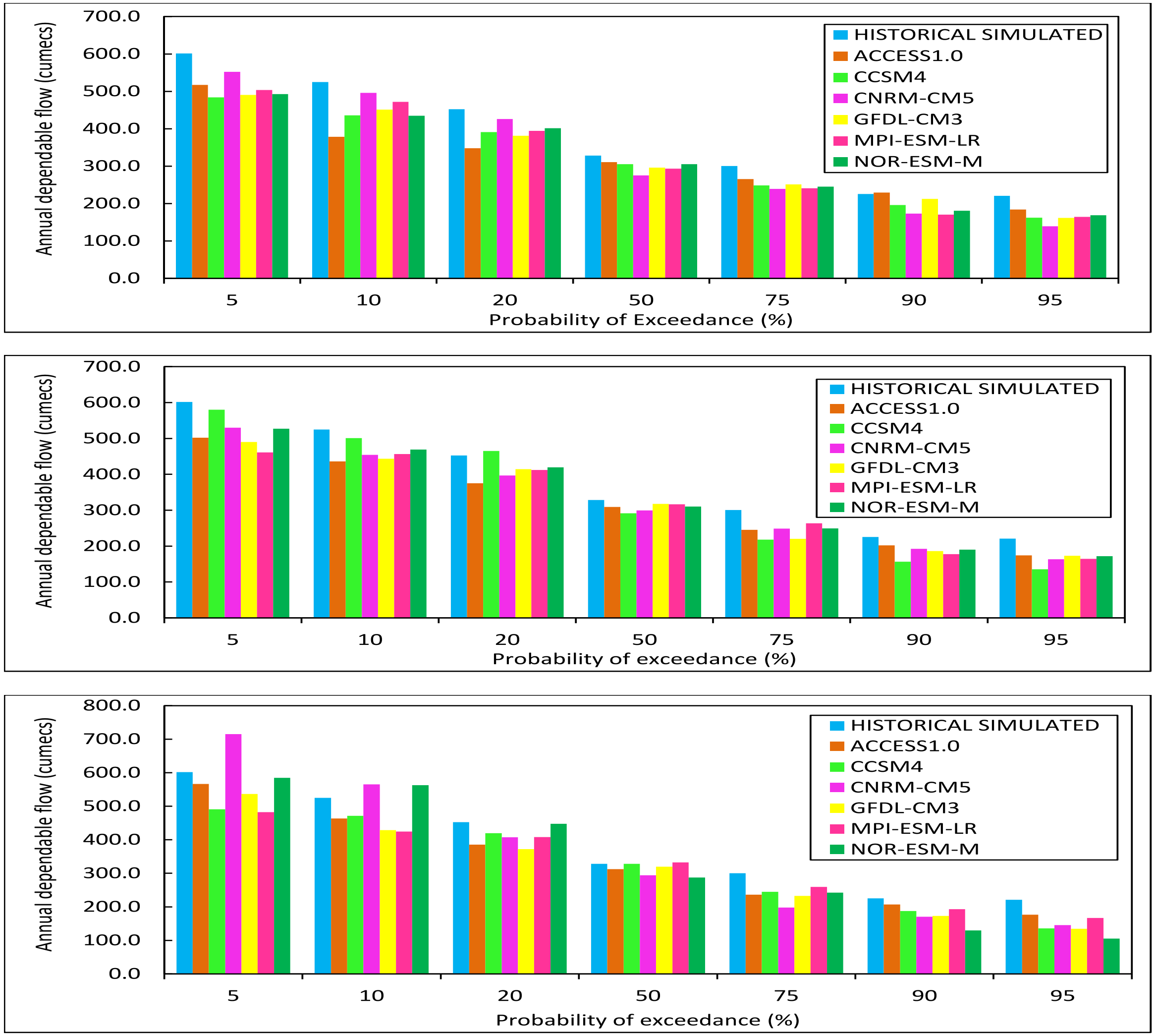
RCM	Time horizon	RCP4.5	RCP8.5
RCM mean	2006-40	1 in 3.50	1 in 2.69
	2041-70	1 in 2.73	1 in 2.61
	2071-99	1 in 2.60	1 in 2.26

Average daily maximum temperature : CCSM4

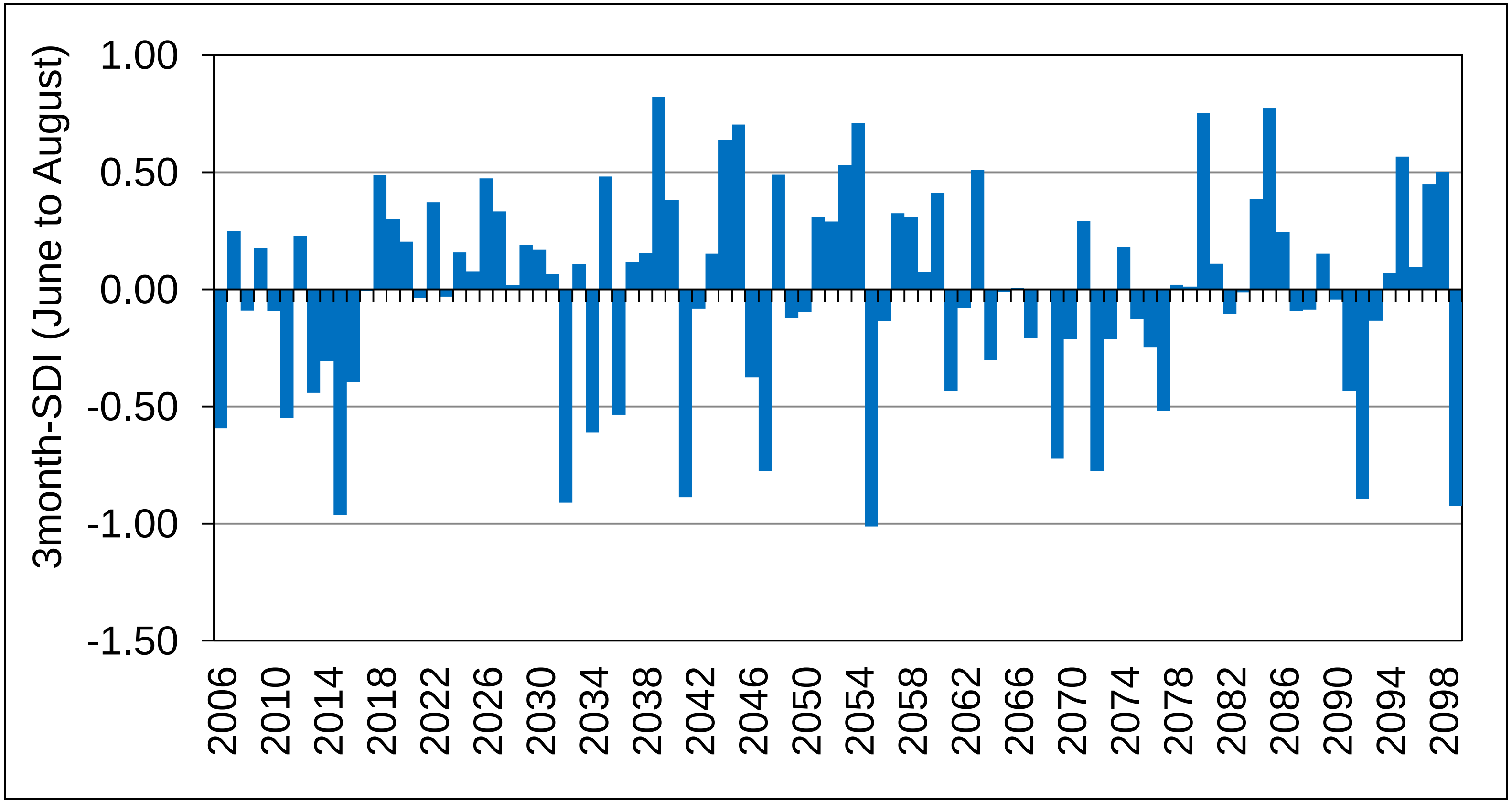
Time horizon	Maximum of MaxT (ºC)		Minimum of MaxT (ºC)	
Scenario	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2006-40	45.67	46.06	21.84	22.40
2041-70	45.64	46.20	21.13	21.43
2071-99	46.22	46.65	22.28	22.78

The summer days, warmer days as well as the summer nights are projected to increase in all future time horizons

Future scenario: Lower water availability

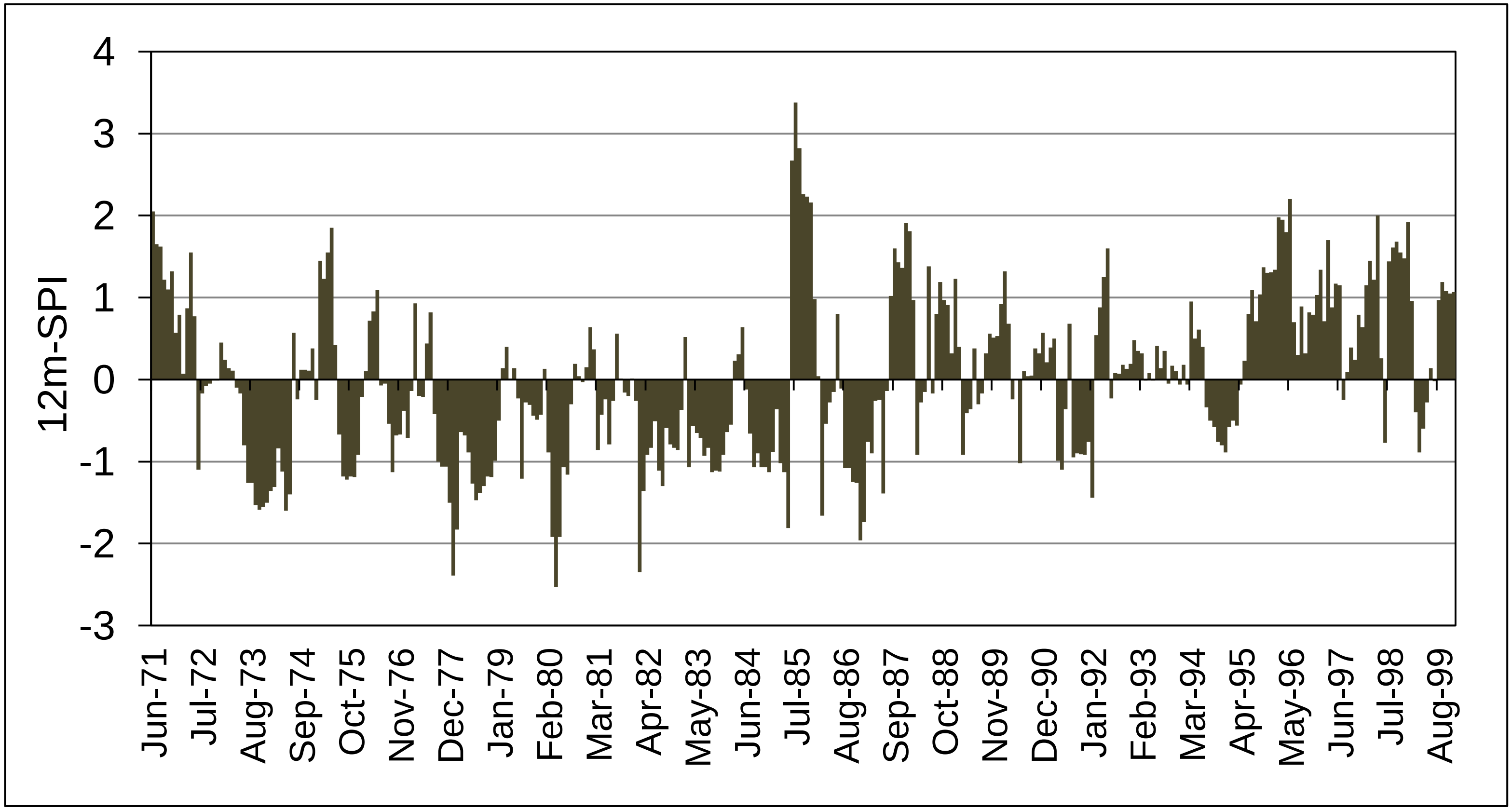


Future scenario: More surface water droughts



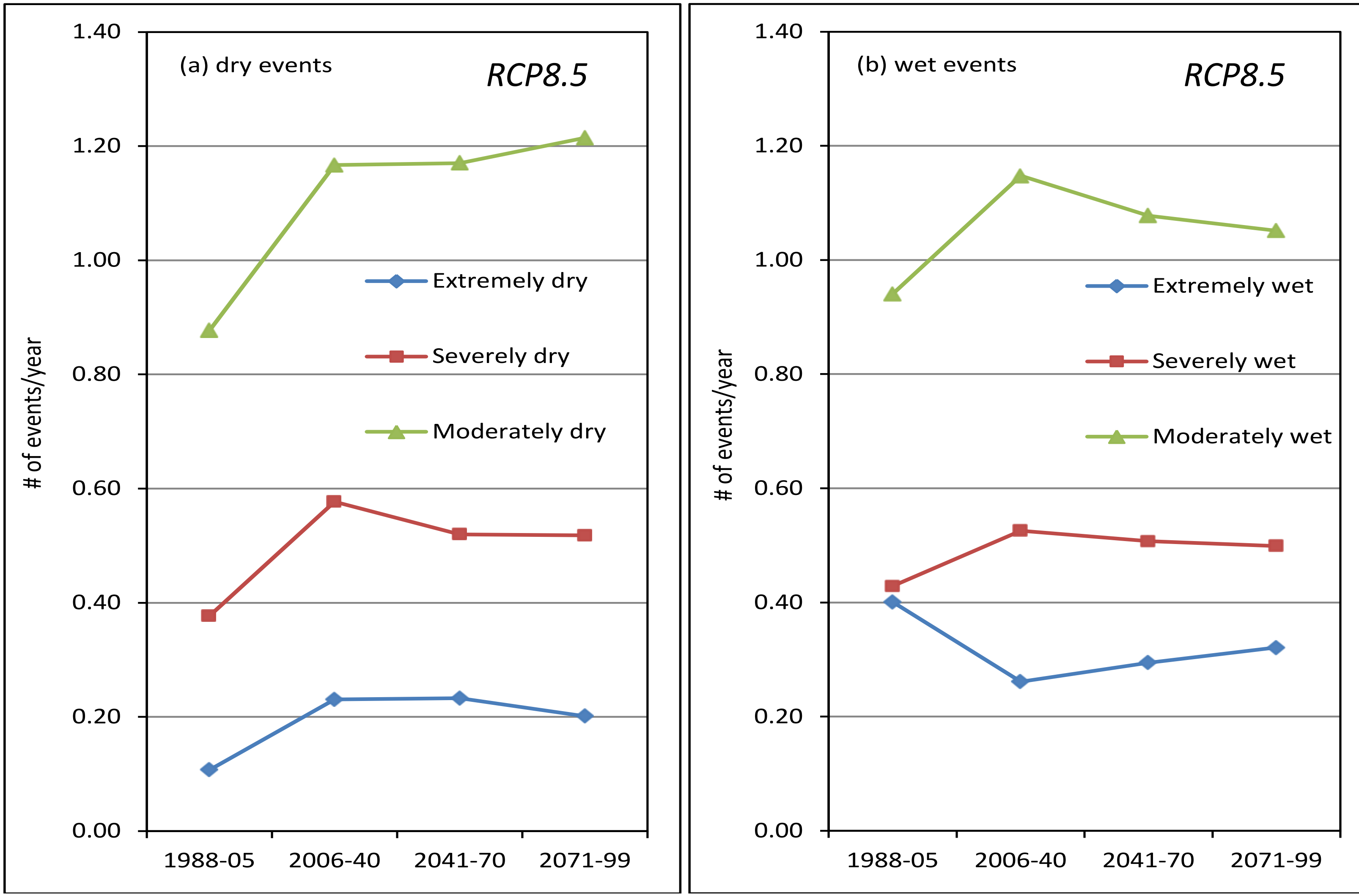
Hydrological drought scenario at Barmanghat (RCP4.5)

Future scenario: More groundwater droughts



Groundwater Drought Scenario RCP8.5

Increased frequency of dry and wet events



Conclusions

- SWAT can be effectively used for hydrologic modelling of large river basins and used effectively for scenario analysis.
- Increasing maximum and minimum temperature during the historical and all future time-horizons.
- Higher extreme rainfall events in the recent and future time-horizons.
- Lower water availability during all future time-horizons.
- Magnitude of low flows and high flows to decrease in future time-horizons.
- More frequent droughts in all future time-horizons.
- Simultaneous occurrences of droughts and wet events with changing rainfall pattern with frequent dry spells calls for optimal water utilisation.
- Supply-side management of the available water coupled with demand-side management can be considered as a viable climate change adaptation tool