Impacts of Climate Variability and Climate Change on Water Resources in the Sabarmati River Basin

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Outline

- Introduction
- Science Questions & Objectives
- Approach
- Progress
- References

Introduction

- The **western India** including the Sabarmati River basin (SRB) has experienced **changes in precipitation and air temperature** during the last 50 years (Mishra et al., 2012b)
- Approximately **75 %** of the area in the SRB is under **agriculture** and is irrigated either by **surface or groundwater resources**
- Monsoon season **precipitation** (Interestingly) and **groundwater withdrawal** for irrigation have **increased** in Gujarat during the period of 1951-2007 (Mishra et al., 2012b, Rodell et al., 2009)

Science Questions

1. How have **hydrologic conditions** associated with soil moisture, evapotranspiration, surface and subsurface runoff, groundwater levels, and stream flow changed during the last 50 years in the SRB?

2. How have **hydrological extremes** changed during the last 50 years and how these are likely to change during the projected future climate in the SRB?

3. How will **water availability and water storage** vary with space and time under the projected future climate change in SRB?

4. To what extent changes in water storage, water availability and hydrological extremes will **influence agricultural production, reservoir operation, urban flooding and flood management?**

Objectives

- To evaluate **hydrological extremes(floods and droughts)** under retrospective and future climate change

- To evaluate **water availability and storage** under retrospective and future climate change

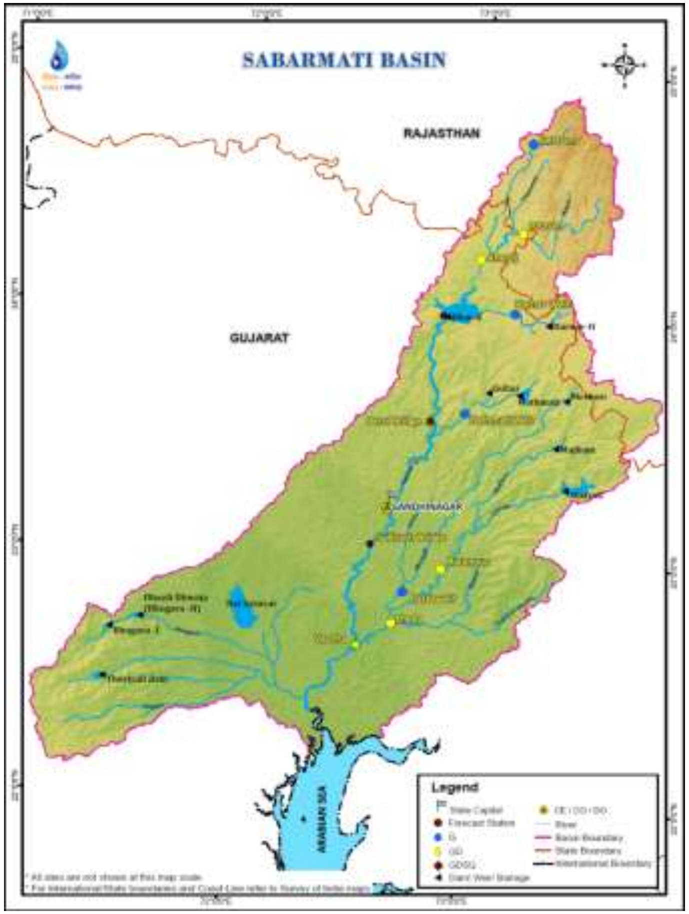
- To analyze effect of hydrologic changes on **agricultural production**, **reservoir operation** and **flood & drought management**

Tasks

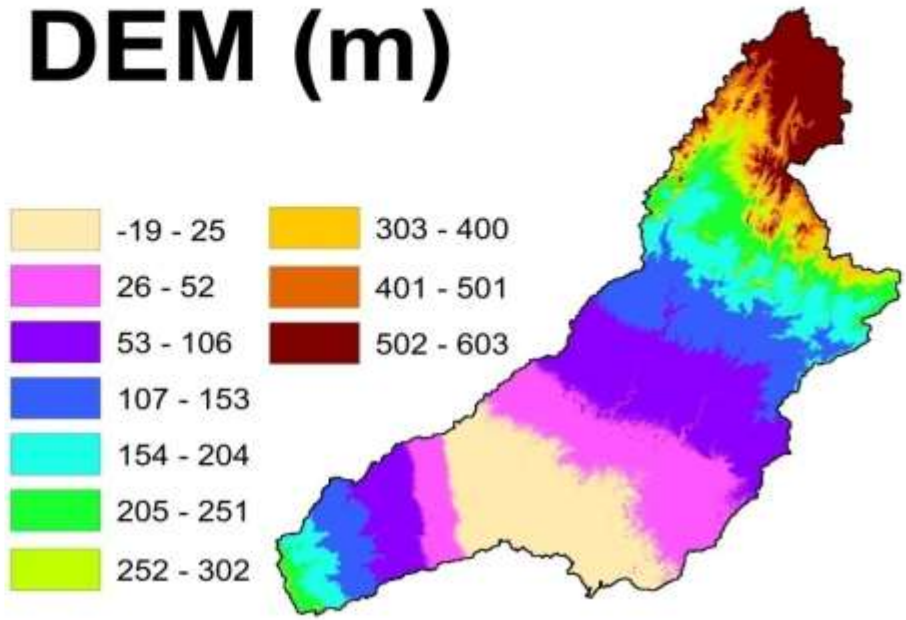
1. **Data collection**
2. **Processing future climate projections**
3. **Development of the hydrological modeling framework**
4. **Optimization of reservoir operation and irrigation planning**
5. **Understanding retrospective and hydroclimatological changes**
6. **Development of hydrologic scenarios for the projected future climate**
7. **Implications of projected hydrological and climate changes**

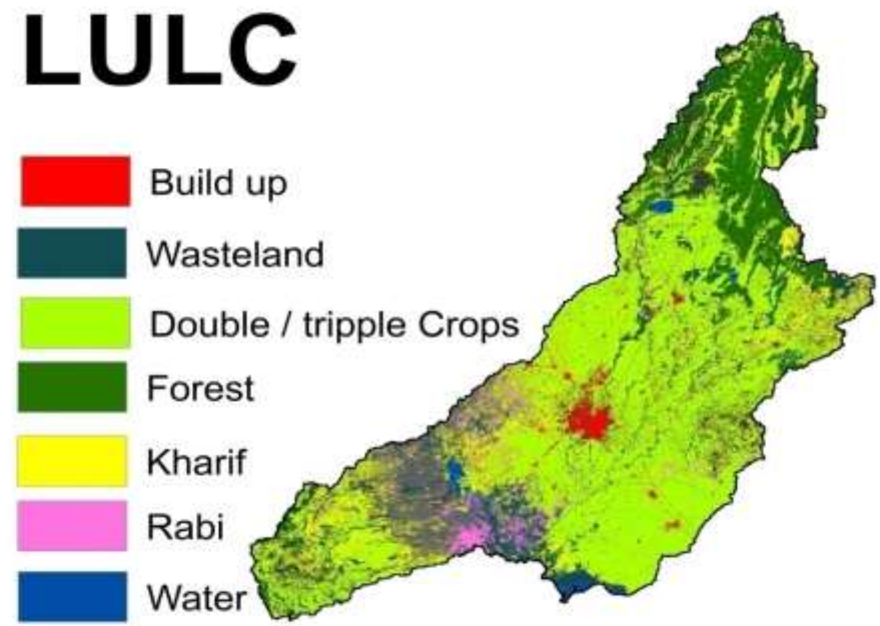
Study Area

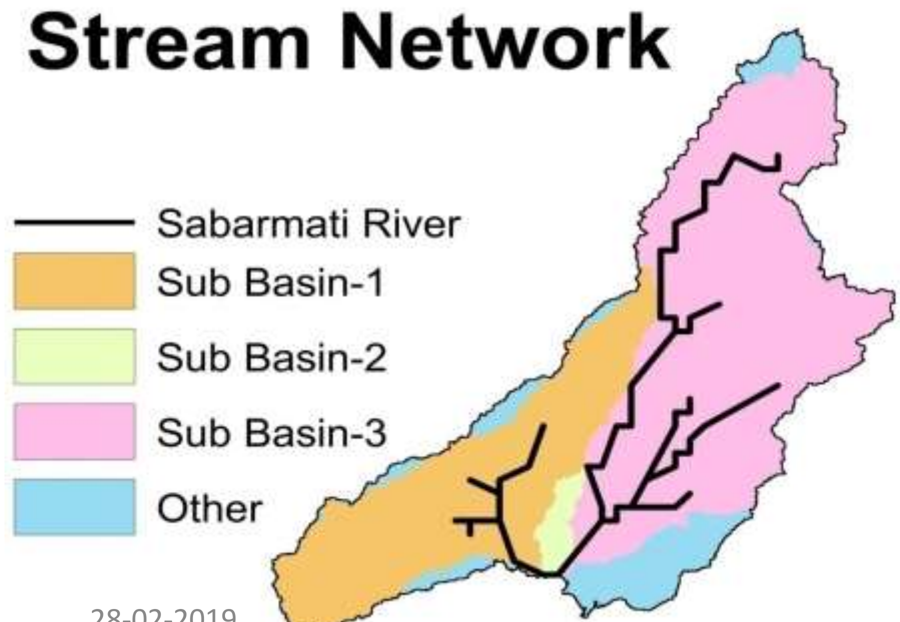
- The Sabarmati River basin originates from Dhebar lake in Rajasthan and meets the Gulf of Cambay of the Arabian Sea
- The total catchment area = 21,674 km^2
- Maximum length is 317 km
- Average annual rainfall is 750 mm

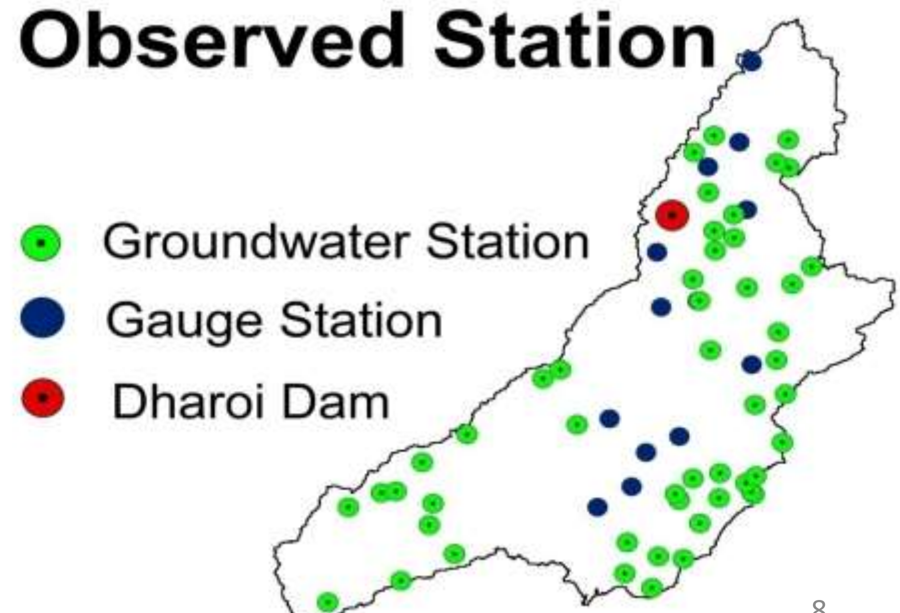


Source:- http://www.india-wris.nrsc.gov.in/

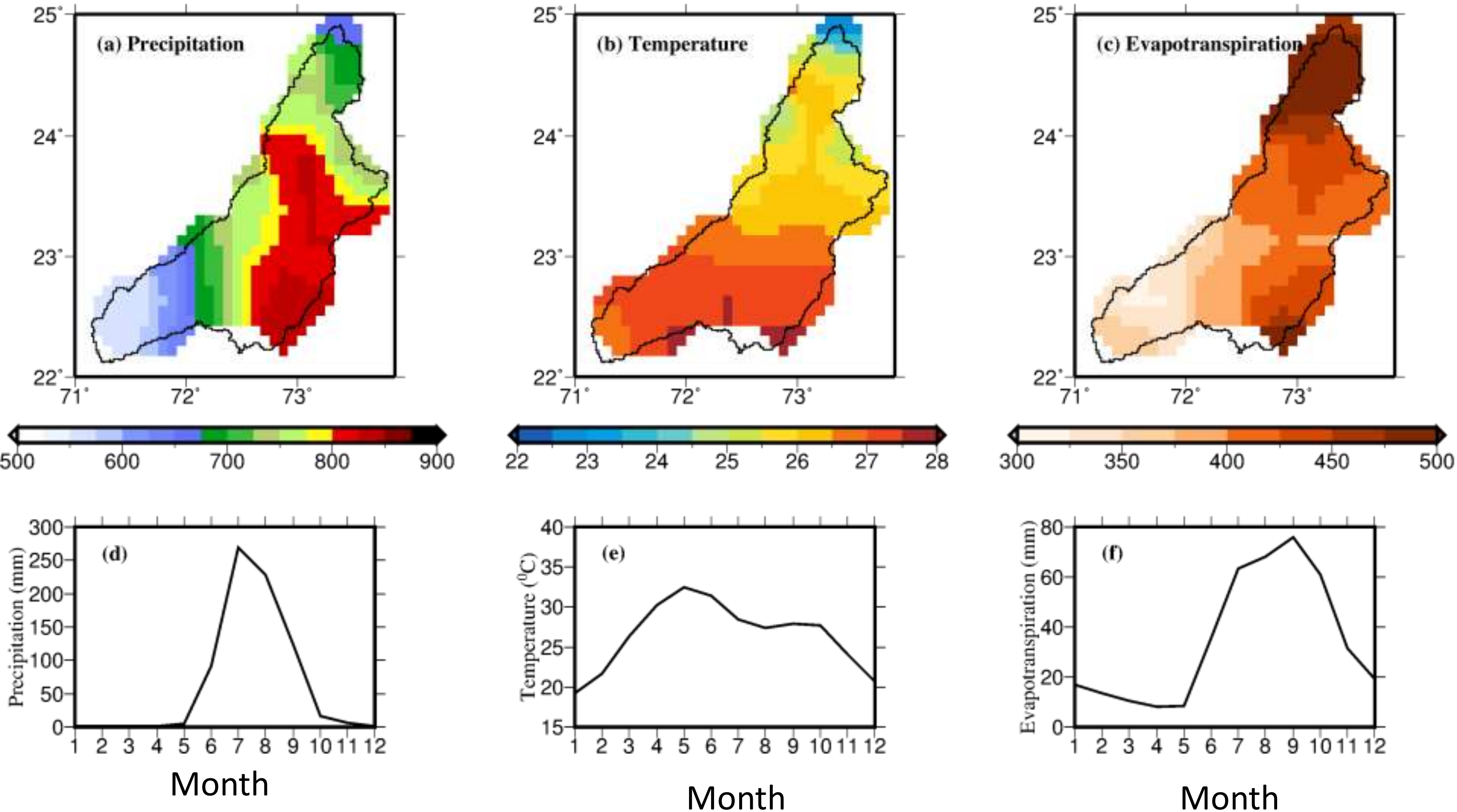

DEM (m)
-19 - 25
26 - 52
53 - 106
107 - 153
154 - 204
205 - 251
252 - 302
303 - 400
401 - 501
502 - 603


LULC
Build up
Wasteland
Double / tripple Crops
Forest
Kharif
Rabi
Water

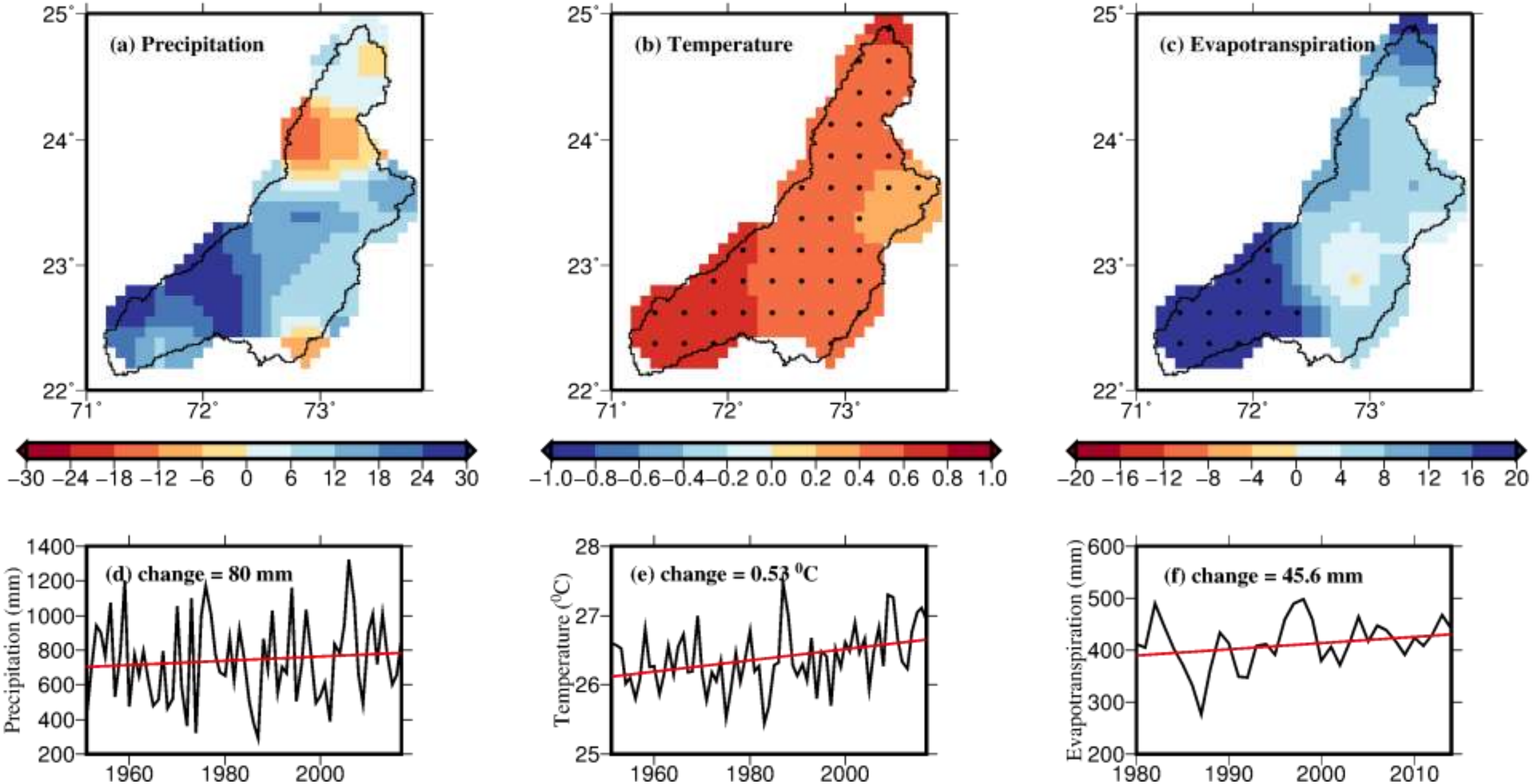

Stream Network
Sabarmati River
Sub Basin-1
Sub Basin-2
Sub Basin-3
Other


Observed Station
Groundwater Station
Gauge Station
Dharoi Dam

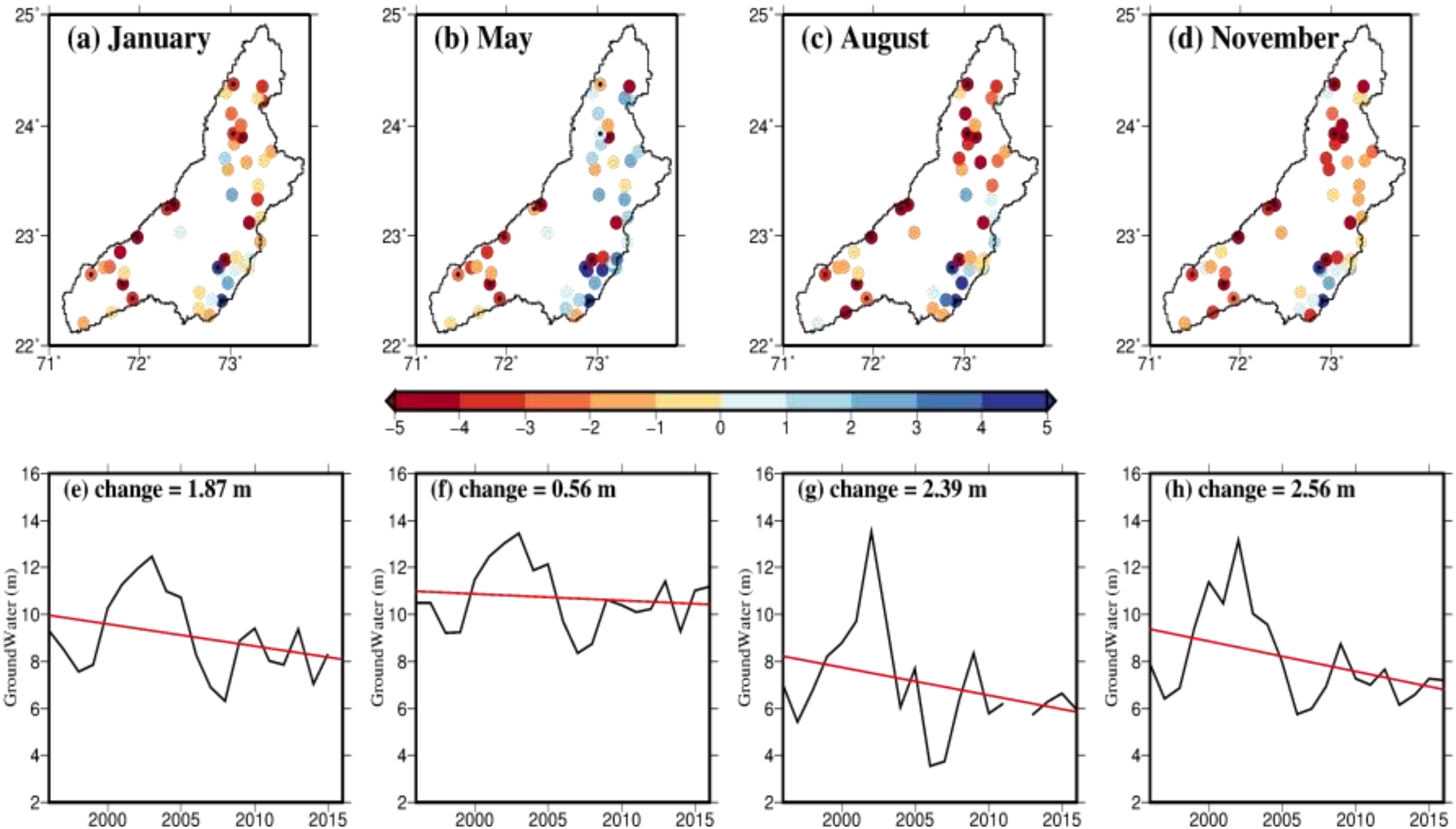
Mean Annual and Seasonal Variation in P, T, ET



Trend in P,T (1951-2017) &ET (1980-2014)

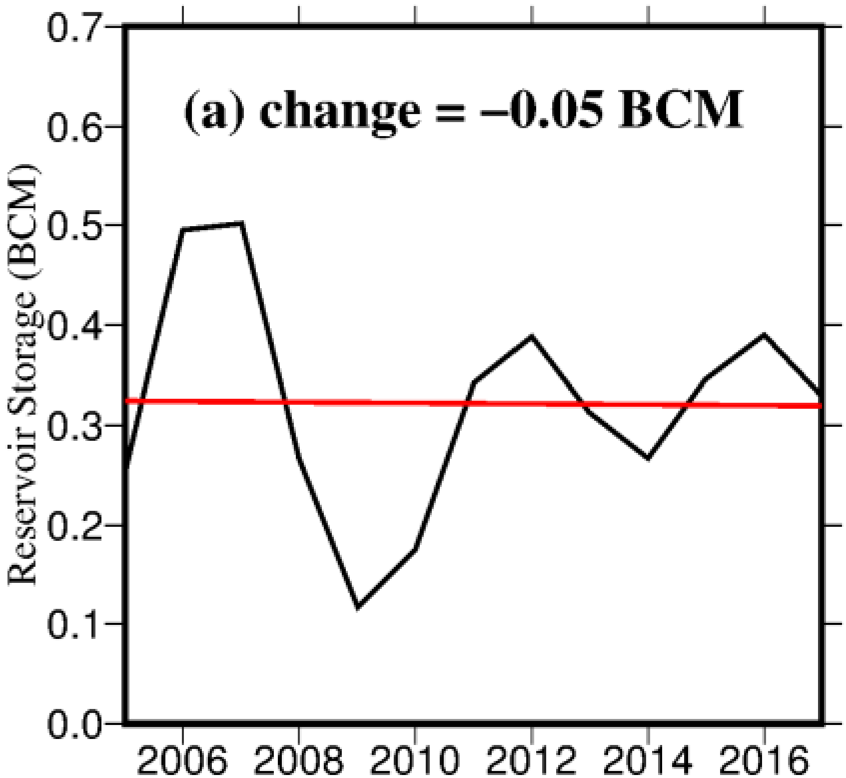


Change in GW Level (1996-2016)

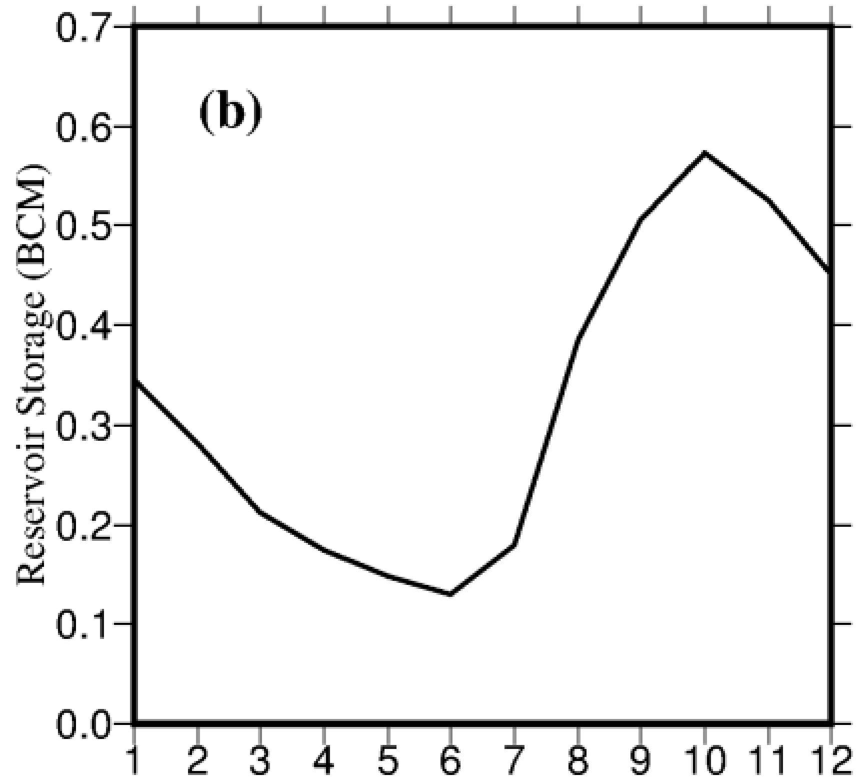


Data Source: CGWB

Dharoi Reservoir Storage Variation (2005-2018)



Year



Month

Approach

1. **Data collection**
2. **Development of the hydrological modeling framework**
   a. Set up Variable Infiltration Curve (VIC) with SIMple Groundwater Model **(VIC-SIMGM)** for SRB
   b. Calibration & validation
3. **Development of an Integrated Drought Index (IDI)**
4. **Understanding of droughts in retrospective scenario**
   a. To determine trends in change in precip/temp/ET/groundwater level (spatially & temporarily)
   b. **Reconstruction of droughts** in retrospective scenario(1950-2017) based on IDI
5. **To evaluate pattern of droughts in SRB under projected future climate**

Datasets

Type of Data	Source
Precipitation, Tmax, Tmin, Wind speed (observed)	Indian Meteorological Department (IMD), NCAR(National Center for Atmospheric Research)
LULC data	NRSC (National Remote Sensing Center)
Soil data	Food and Agriculture Organization (FAO)–Harmonized World Soil Database (HWSD)
Vegetation data	University of Maryland's 1 km vegetation class dataset (Hansen 2006)
Streamflow, Groundwater (observed)	India WRIS (Water Resource Information System) & Central Ground Water Board (CGWB)
Total Water Storage Anomaly (TWSA) Ground Water Storage Anomaly (GWSA)	GRACE (Gravity Recovery and Climate Experiments) (WCL data)
Drought Severity Index (DSI) data	Mu, Qiaozhen, et al. (2013) (ftp://ftp.ntsg.umt.edu/pub/MODIS/Mirror/DSI)

VIC-SIMGM

- Developed by Liang et al. (1994)
- Macro scale semi distributed hydrological model
- Solves water and energy balance within grid

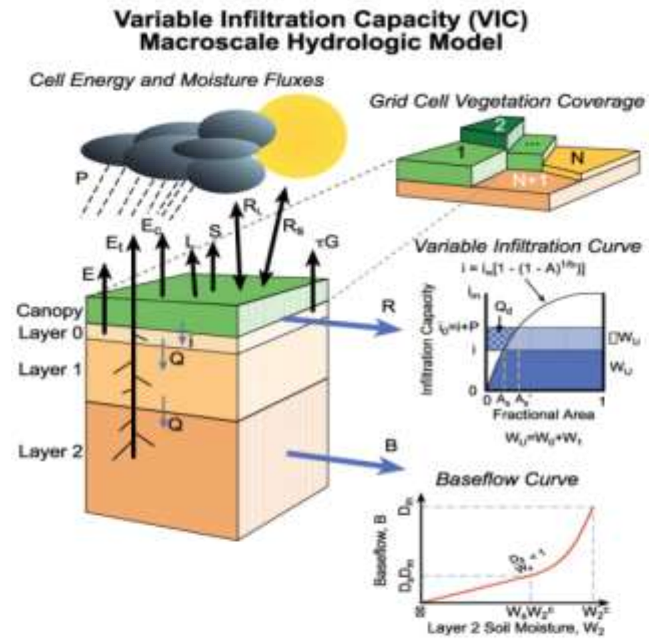
Input Parameters:

1. Forcing (Precipitation, Tmax, Tmin, Wind speed)
2. Soil Information
3. Vegetation Parameter & library

Output Parameters:

- Evapotranspiration, Runoff, Soil Moisture, Groundwater depth, Ground water Recharge/discharge

Source: Liang et al. (1994) & Niu et al. (2007)



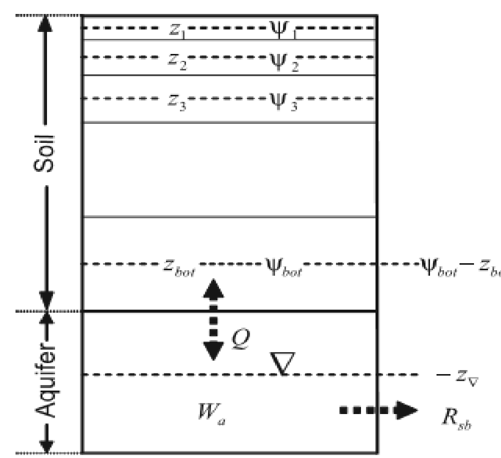


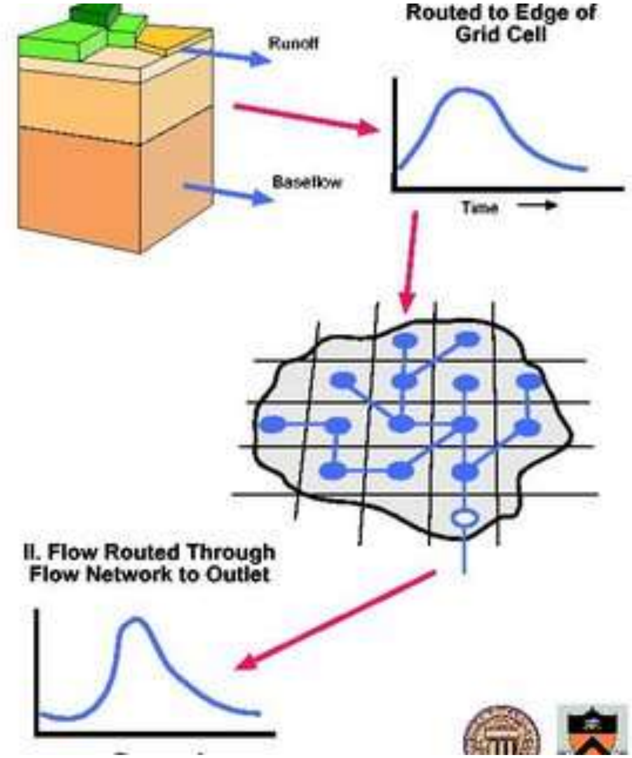
Figure 1. Schematic diagram of the soil layers and an unconfined aquifer. The depth to water table is represented by z_∇. The recharge rate Q is proportional to the difference between the water head at the bottom layer ($\psi_{bot} - z_{bot}$) and that at the water table ($-z_\nabla$). The water head at the water table approximates $-z_\nabla$ for the reason that the capillary pressure head (ψ_{sat}) is negligible compared to the elevation head $-z_\nabla$.

Routing Model

- Developed by Lohmann et al. (1996).
- Simulate streamflow using VIC baseflow and runoff.
- Routing within a grid cell and river routing.
- Unit hydrograph and linearized Saint-Venant equation.

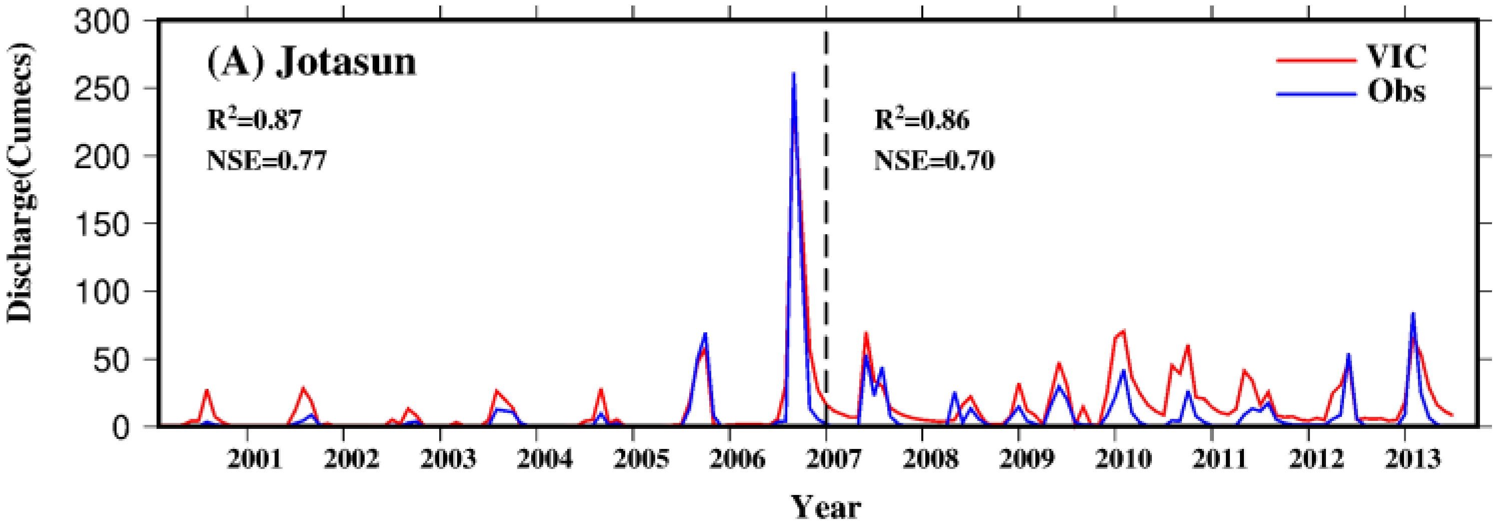
Input parameters

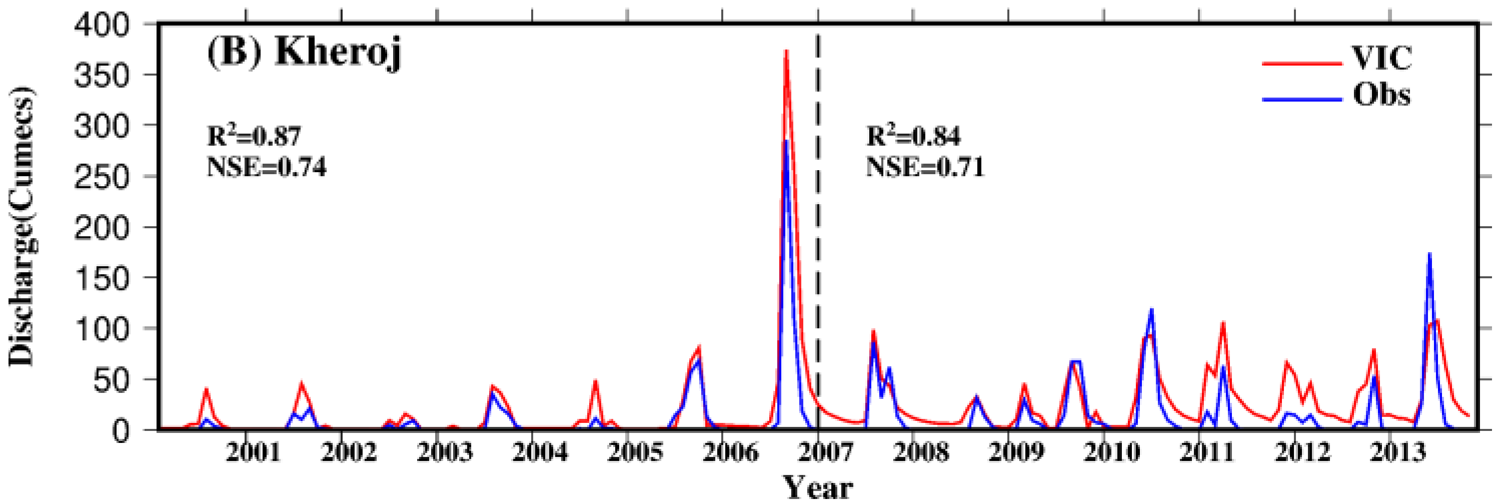
1. DEM
   1.1 Flow direction
   1.2 Flow fraction
2. Station location
3. Daily baseflow and runoff



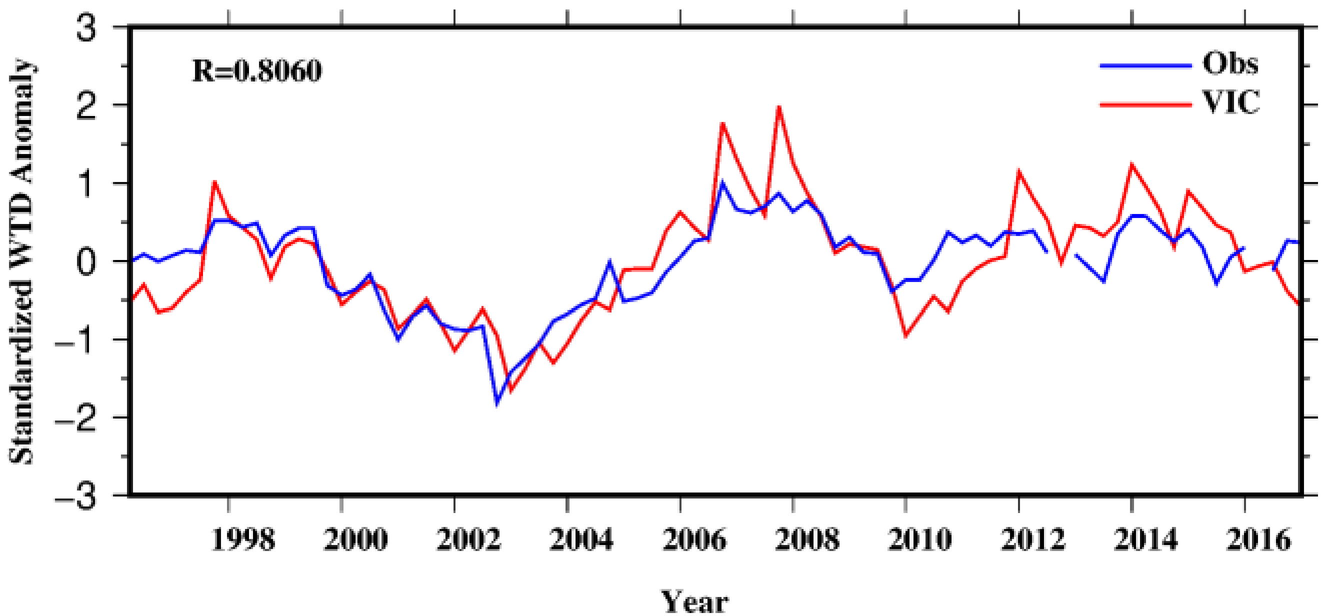
Source: Gao et al. (2010)

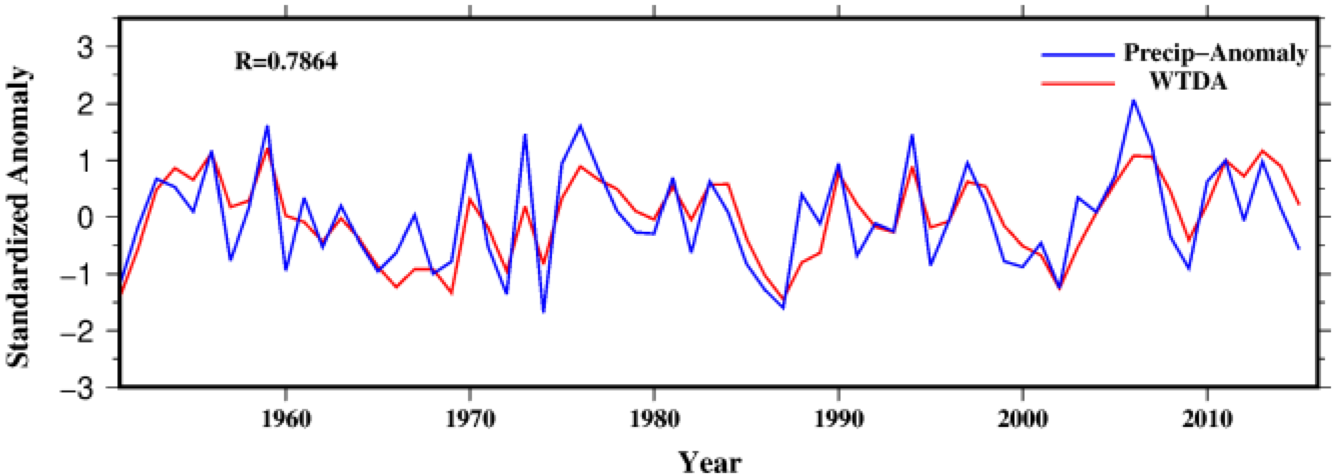
Calibration and Validation





Groundwater Depth Comparison





Development of Integrated Drought Index (IDI)

- **Simple mean approach**
- **Probabilistic approach (Using Copula)**

Simple mean approach

- We identified correlation with different scale (1,2,3,4,6,8,12,18,24,36,60) SPI, SSI and SRI with keeping different scale SGI as reference.
- The best possible set of highly correlated indices were used to calculate IDI

IDI= (24M SPI + 12M SRI + 1M SSI + 1M SGI)/4

Problem:

- By doing simple mean only long term droughts could be captured
- We missed short term droughts

Probabilistic Approach(using Copula)

- IDI is developed using joint distribution function (Gaussian copula) of precipitation (SPI), soil moisture(SSI), groundwater (SGI) and runoff (SRI) for overall meteorological, agricultural and hydrological drought characterization.
- **12M SPI, 4M SRI, 1M SSI, 1M SGI** are considered as random variables A, B, C, D respectively, the joint distribution with cumulative probability p can be expressed as

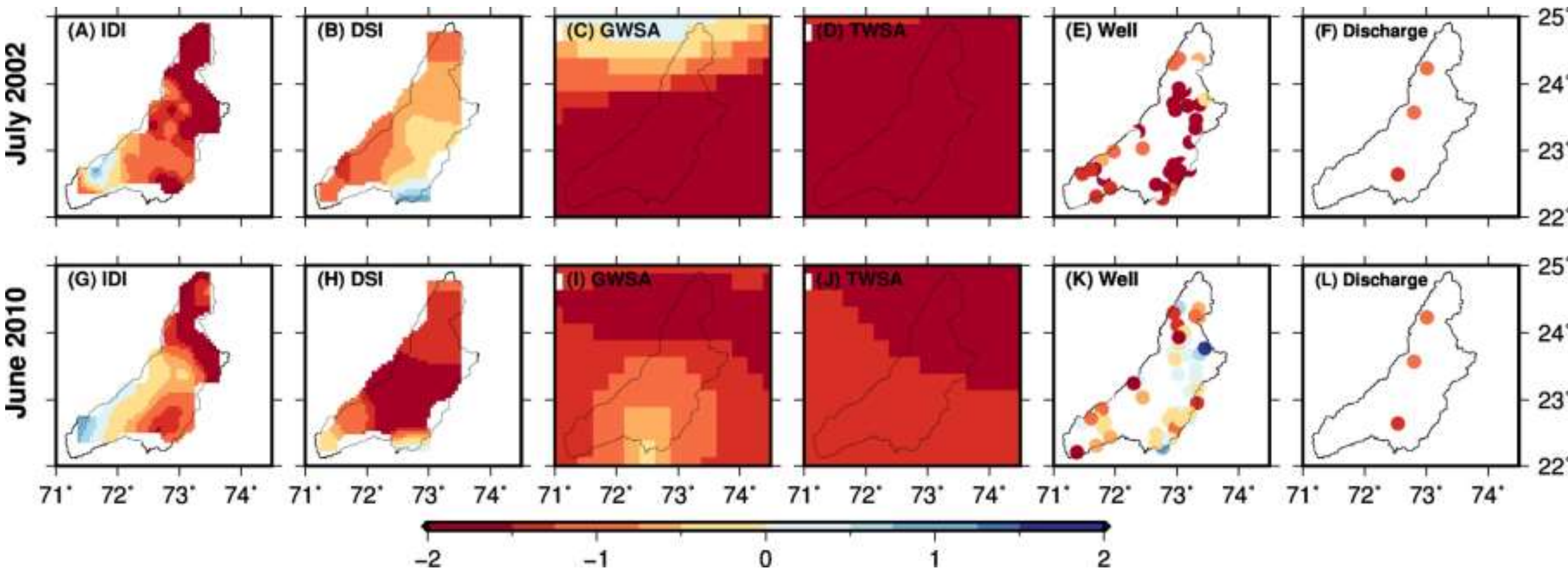
$$p=C[F(A), F(B), F(C), F(D)]$$

  - C=Gaussian Copula,
  - F(A), F(B), F(C), F(D)= empirical cumulative distribution for random variable A,B,C,D respectively.

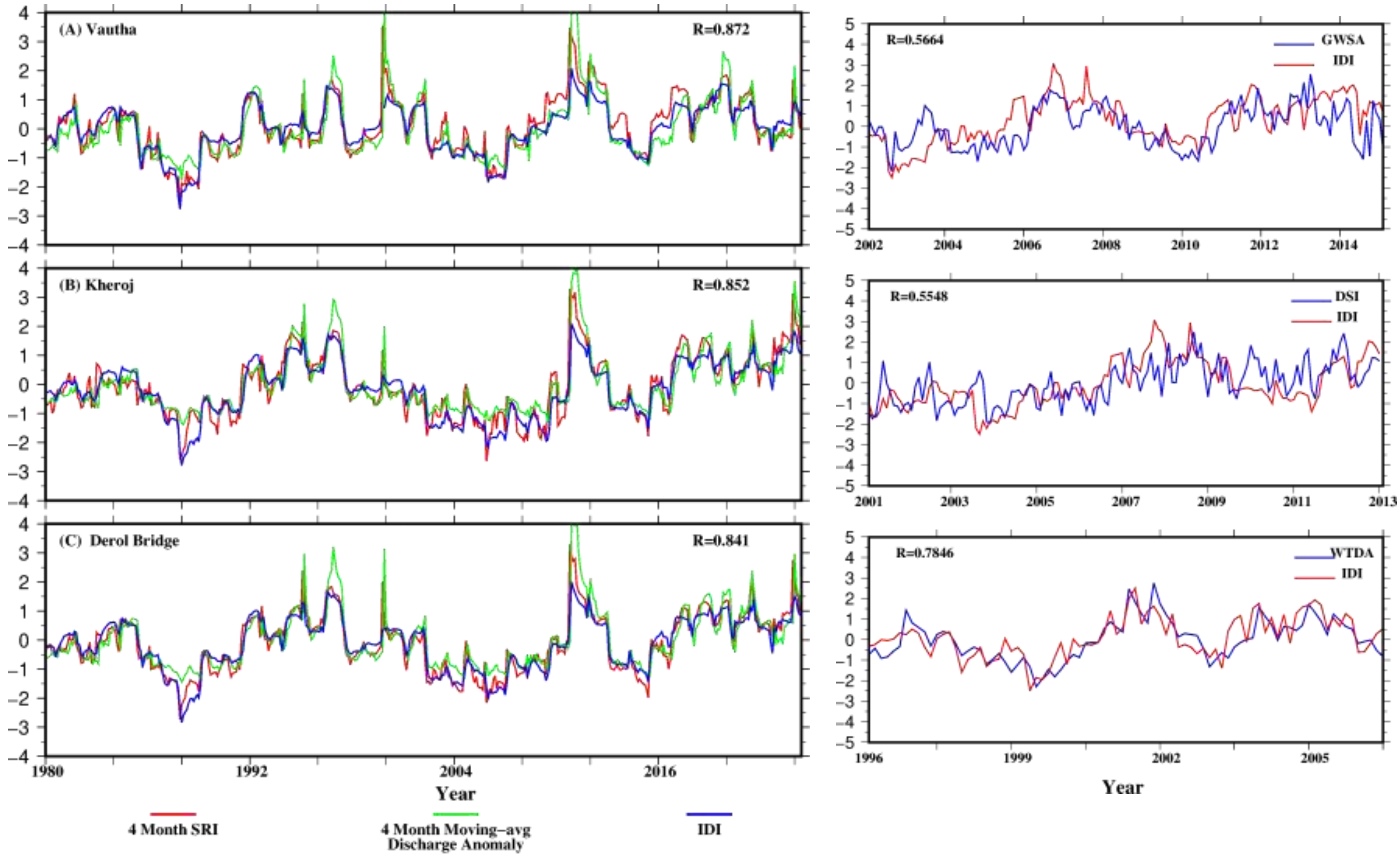
$$IDI = \psi^{-1} (p)$$

ψ=standard normal distribution function

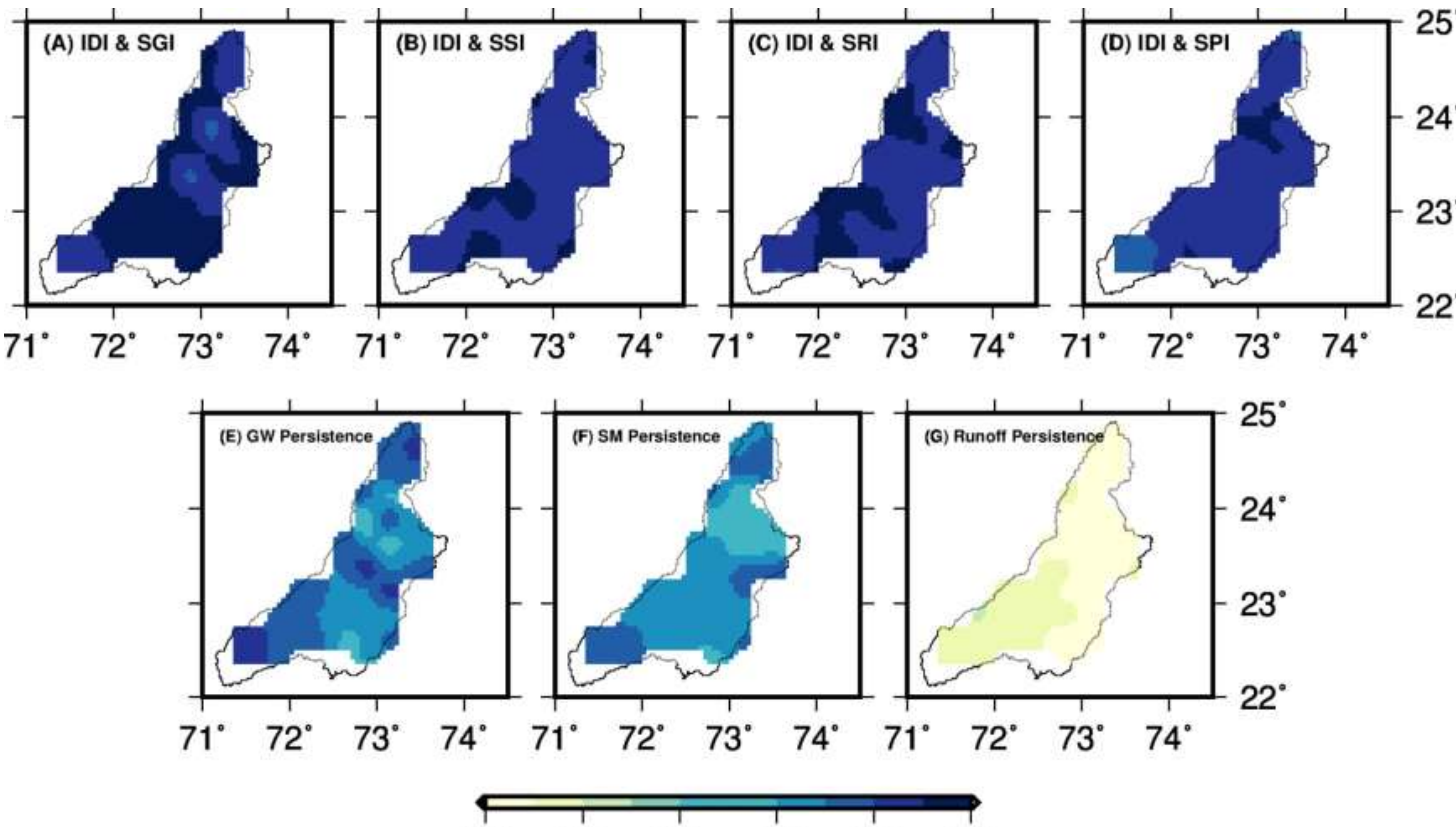
Validation of IDI



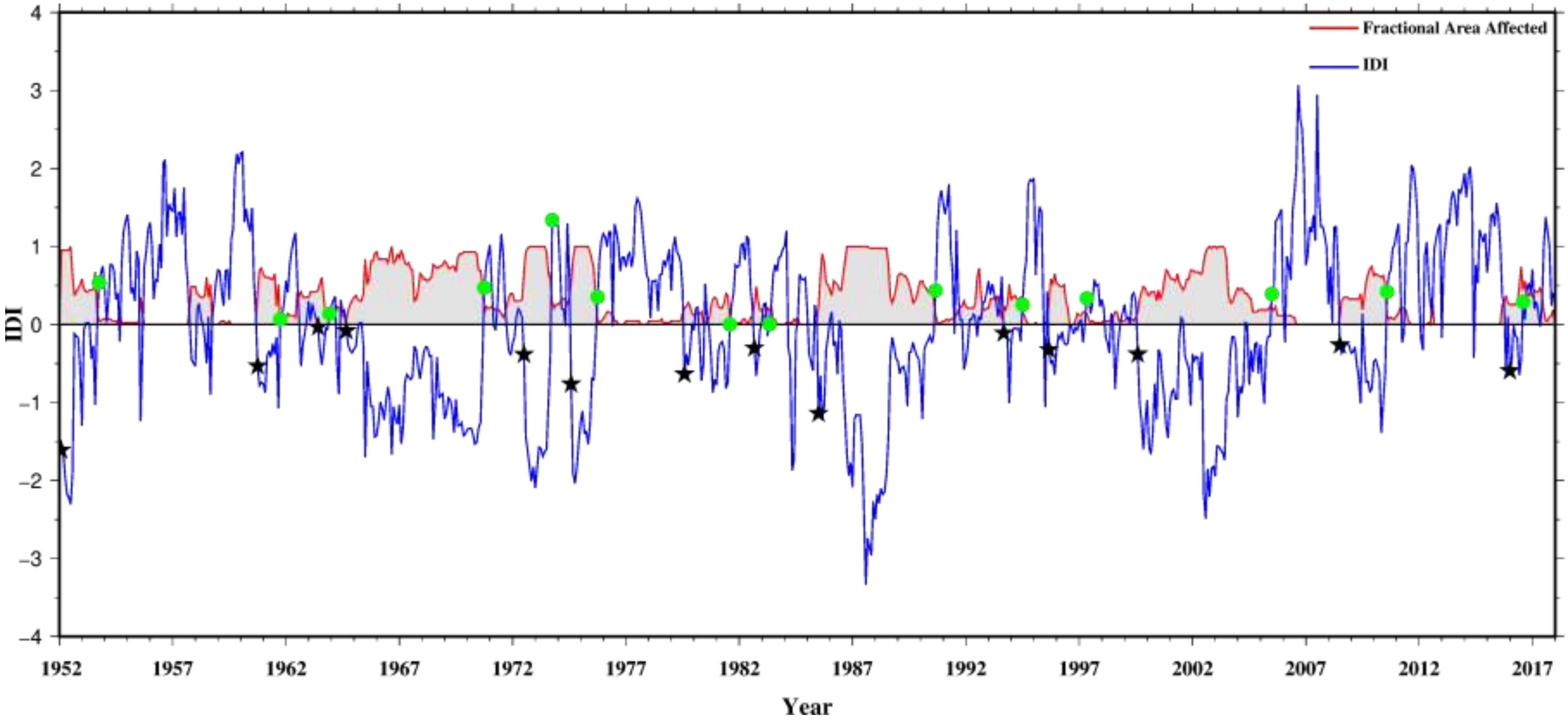
Validation of IDI



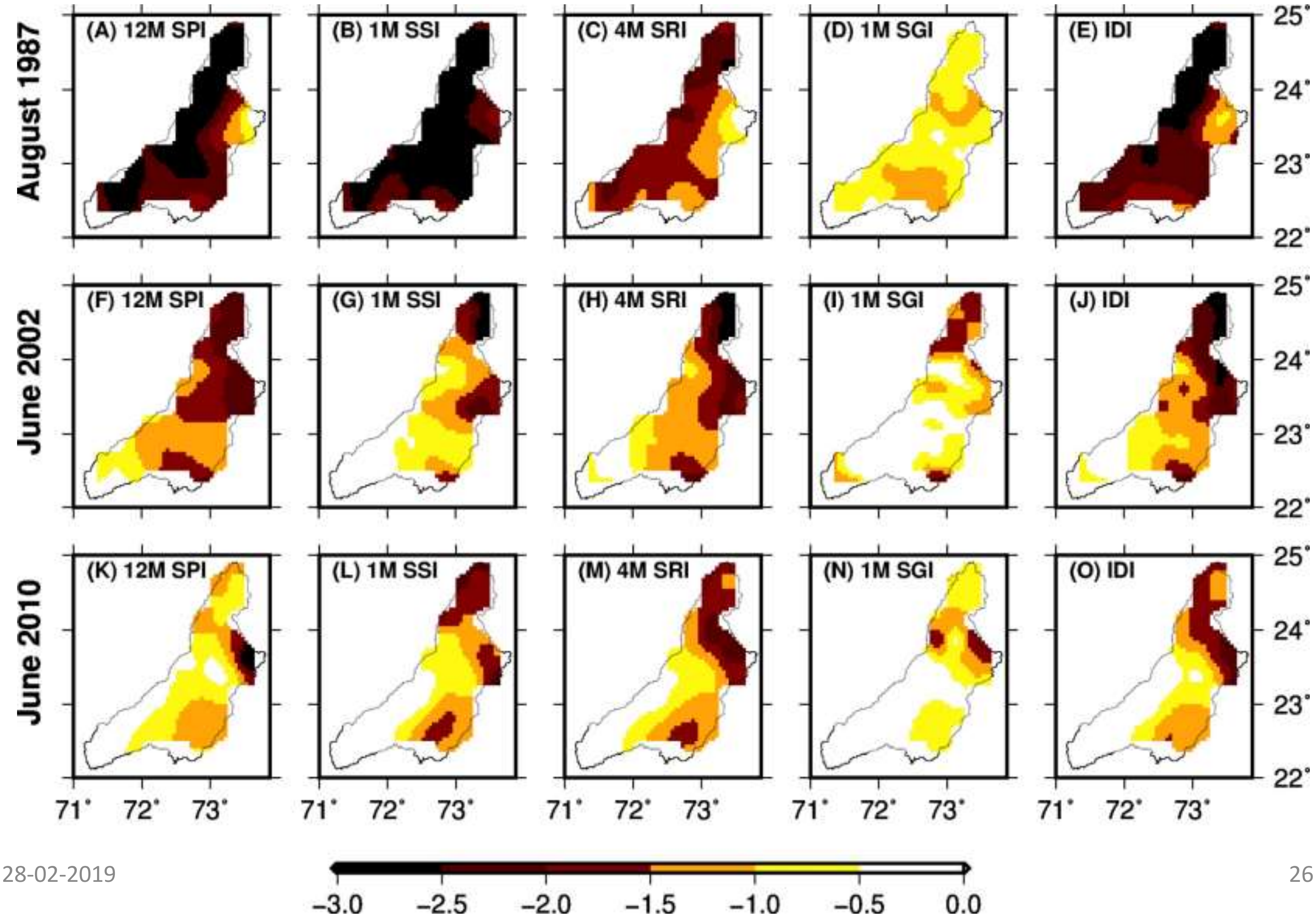
Results: Correlation of IDI with other Indices & Persistence check



Characterization of Drought based on IDI



Spatial Plot for 3 Drought Events

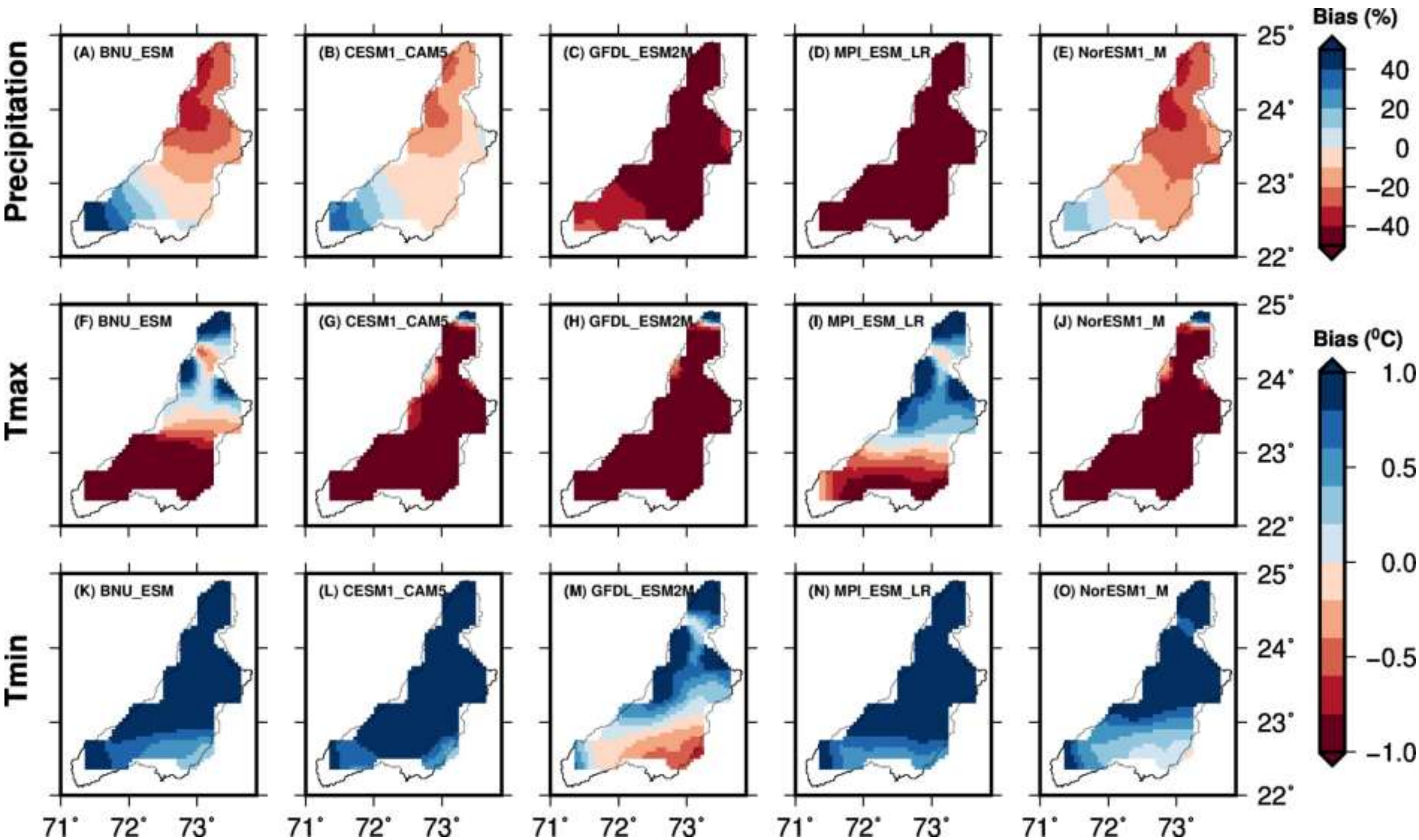


Future Analysis

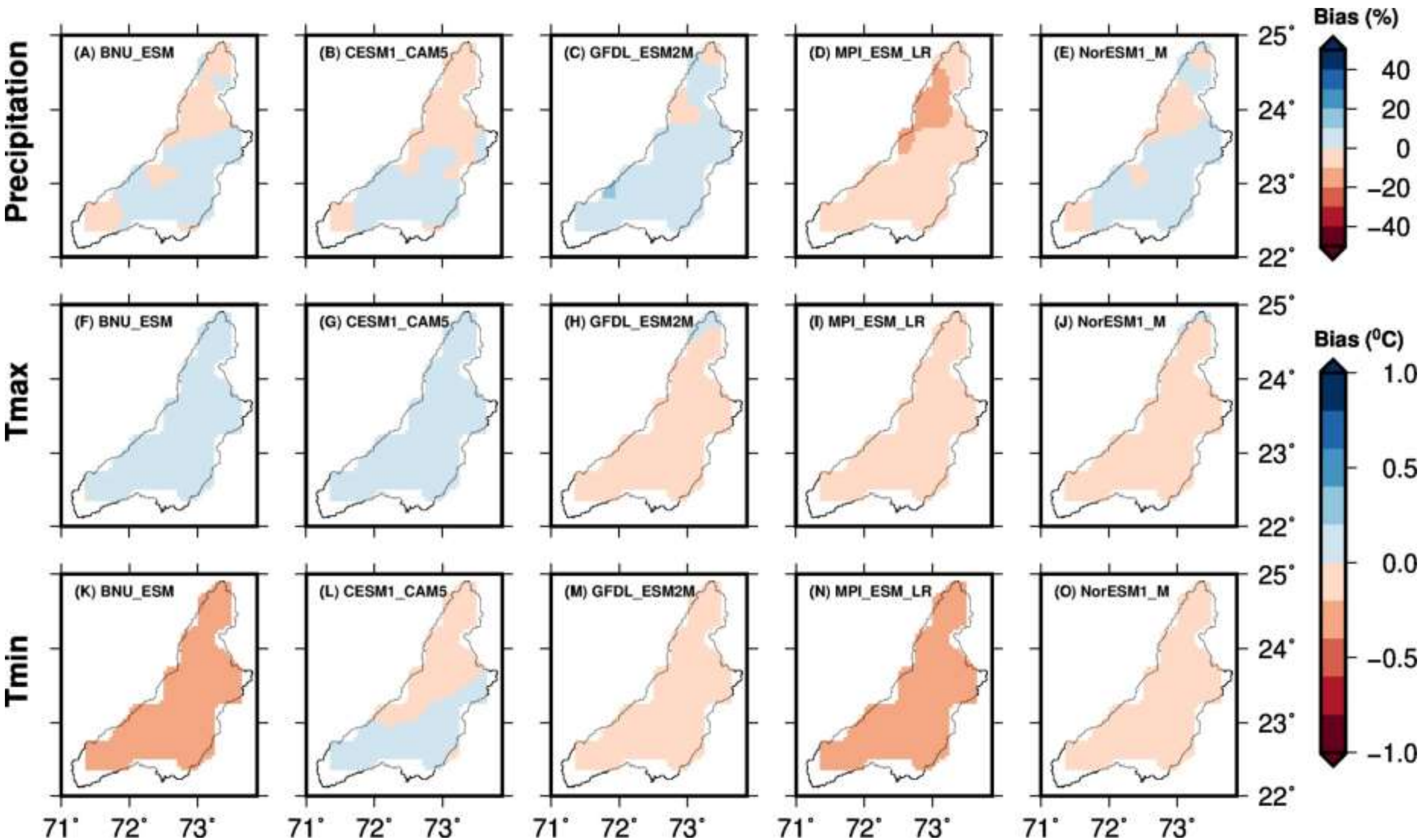
5 best performing CMIP5-GCMs based on **Ashfaq et al.,(2017)** are downscaled and bias corrected at 0.25 degree.

- **BNU-ESM**
- **CESM1-CAM5**
- **GFDL-ESM2M**
- **MPI-ESM-LR**
- **NorESM1-M**

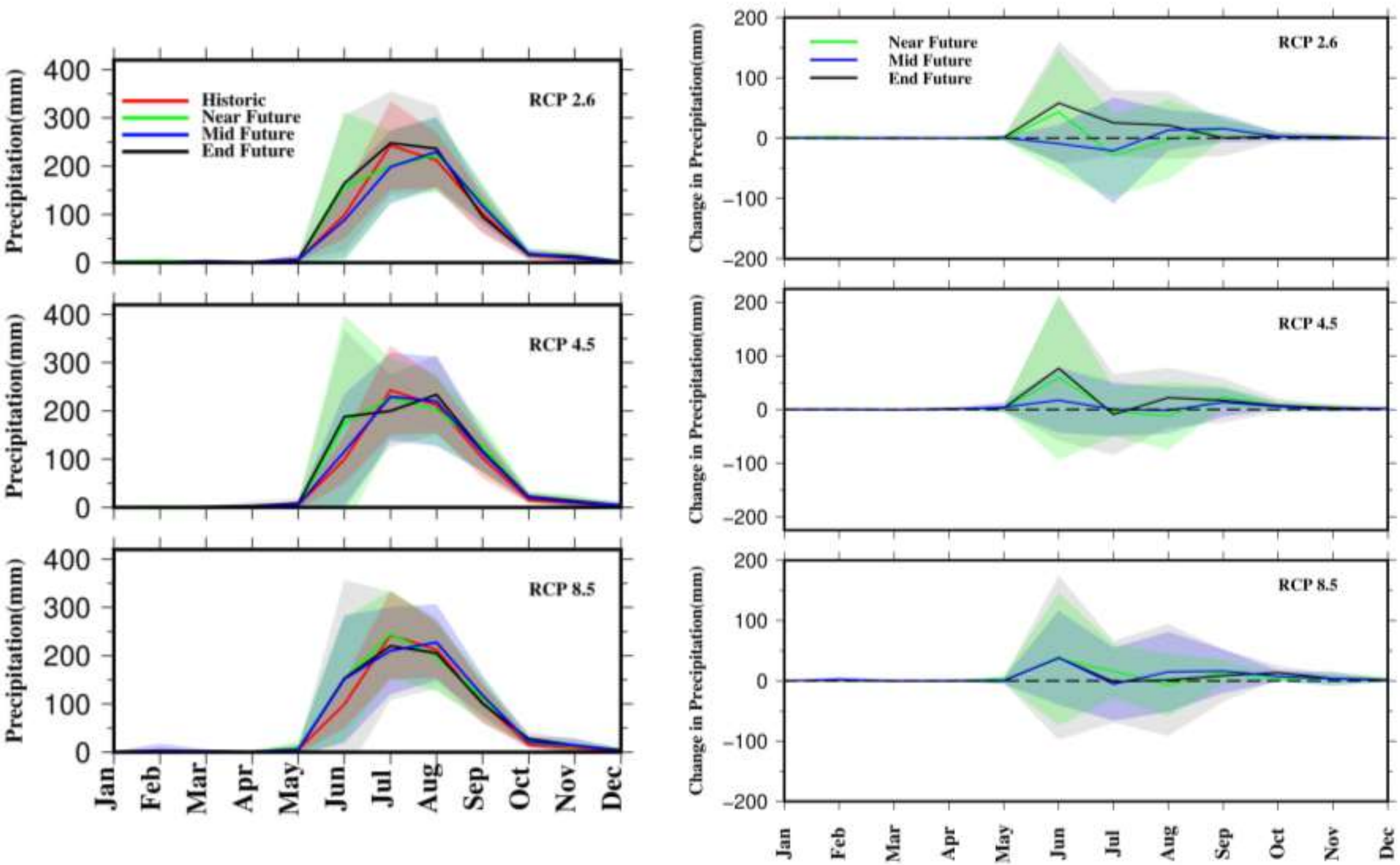
Before Bias Correction



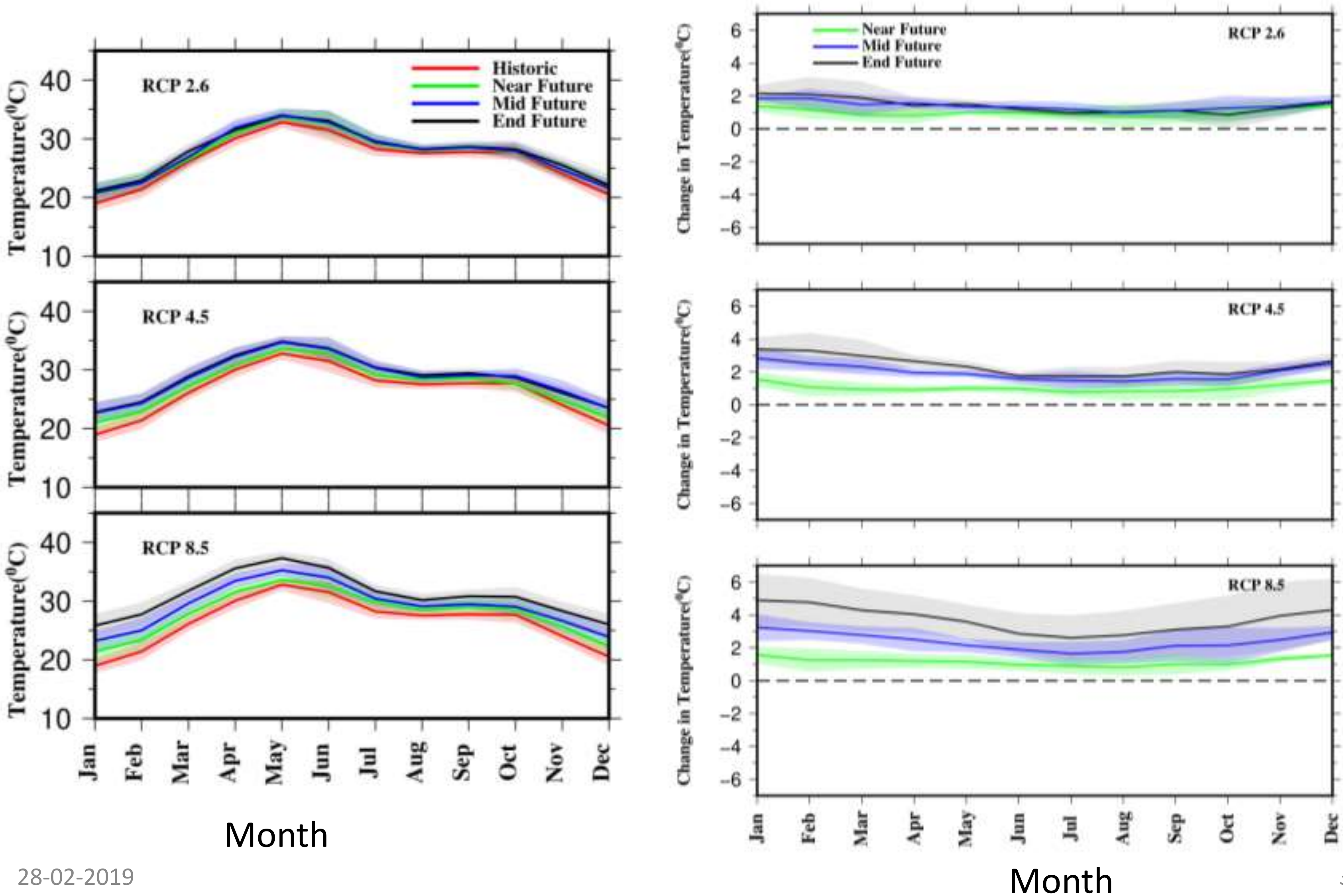
After Bias Correction



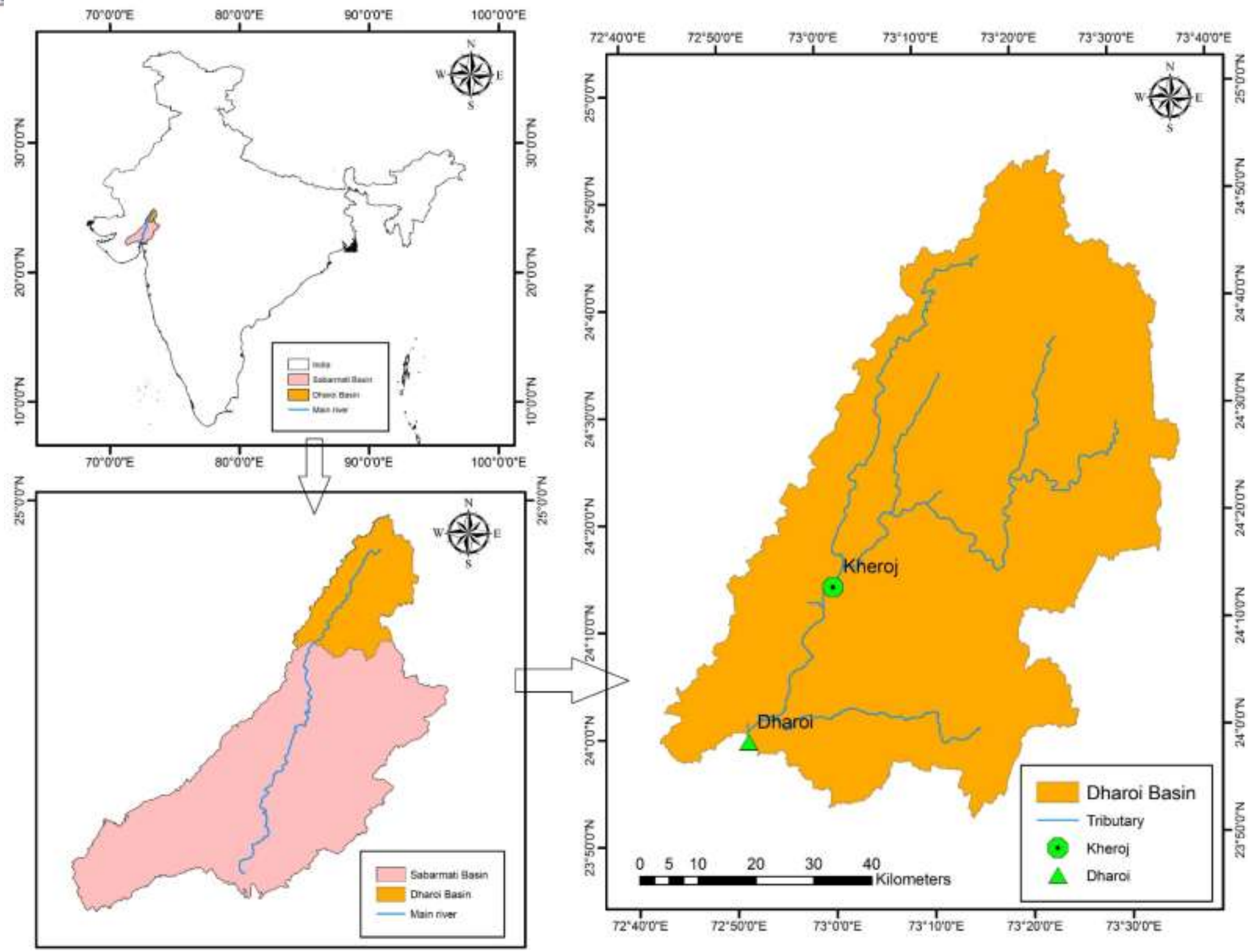
Future Projections (Precipitation)



Projected Changes (Temperature)

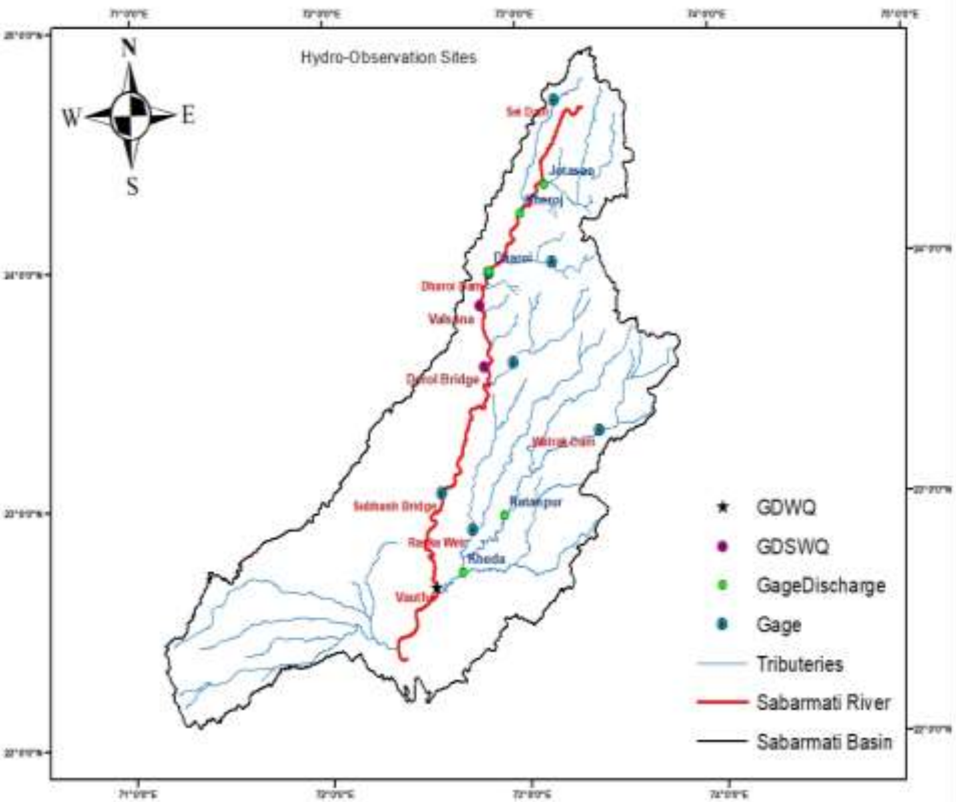


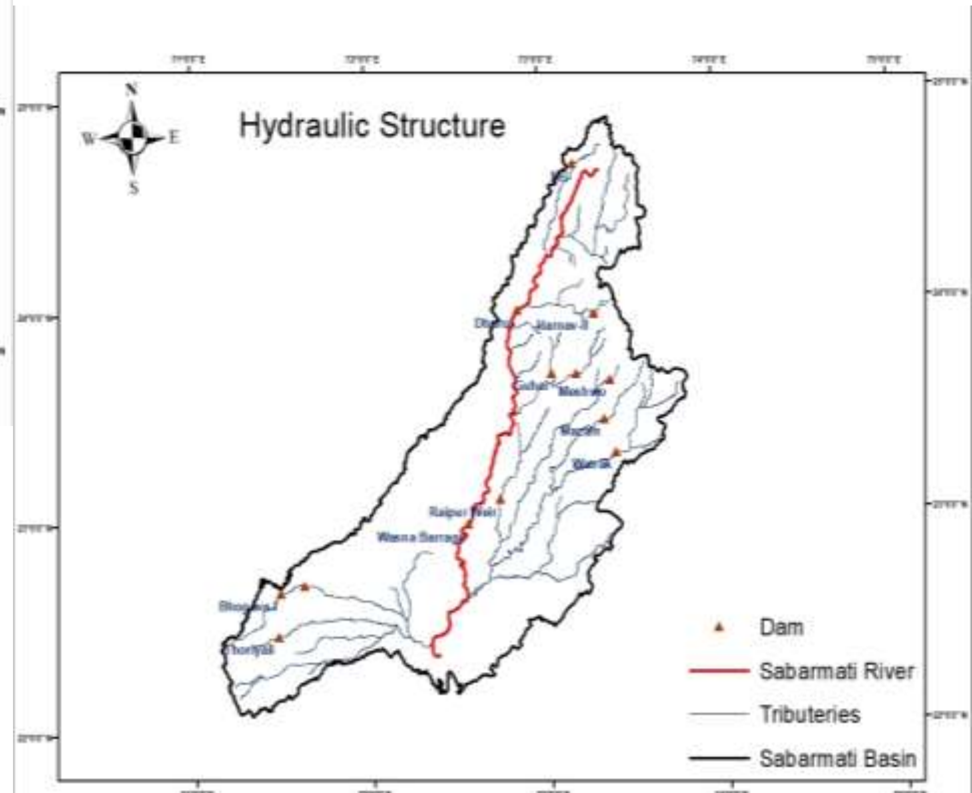
STUDY AREA



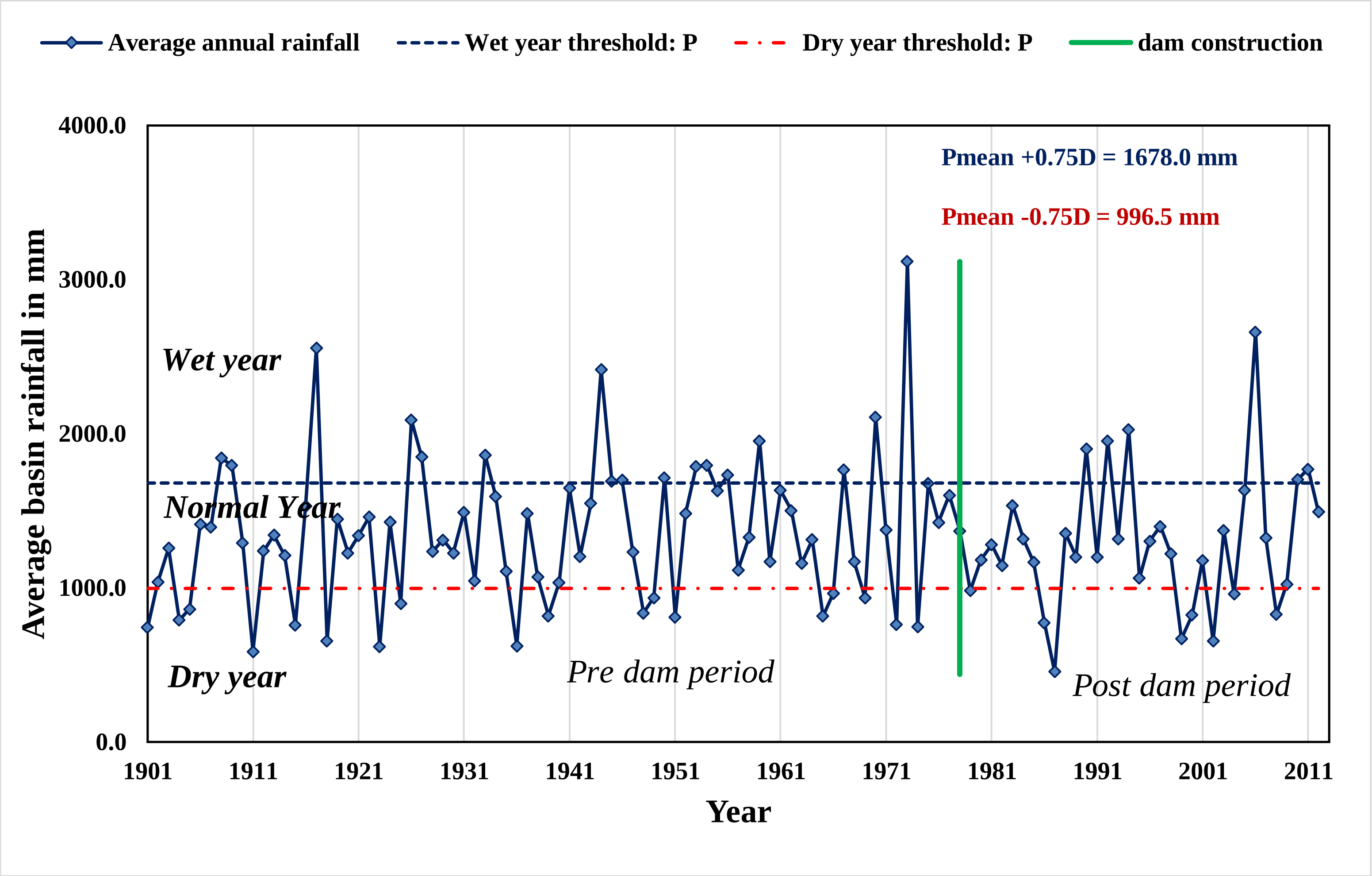
70°0'0"E
80°0'0"E
90°0'0"E
100°0'0"E
30°0'0"N
20°0'0"N
10°0'0"N
25°0'0"N
Sabarmati Basin
Dharoi Basin
Main river
72°40'0"E
72°50'0"E
73°0'0"E
73°10'0"E
73°20'0"E
73°30'0"E
73°40'0"E
24°50'0"N
24°40'0"N
24°30'0"N
24°20'0"N
24°10'0"N
24°0'0"N
23°50'0"N
Kheroj
Dharoi
0 5 10 20 30 40 Kilometers
Dharoi Basin
Tributary
Kheroj
Dharoi

HYDRO-OBSERVATION SITES OF SABARMATI BASIN





CLASSIFICATION OF METEOROLOGICAL CONDITION IN SABARMATI BASIN (Yoo, 2006)



- **26 years were categorised as Dry year**
- **23 years were categorised as Wet year**
- **64 years were categorised as Normal year**

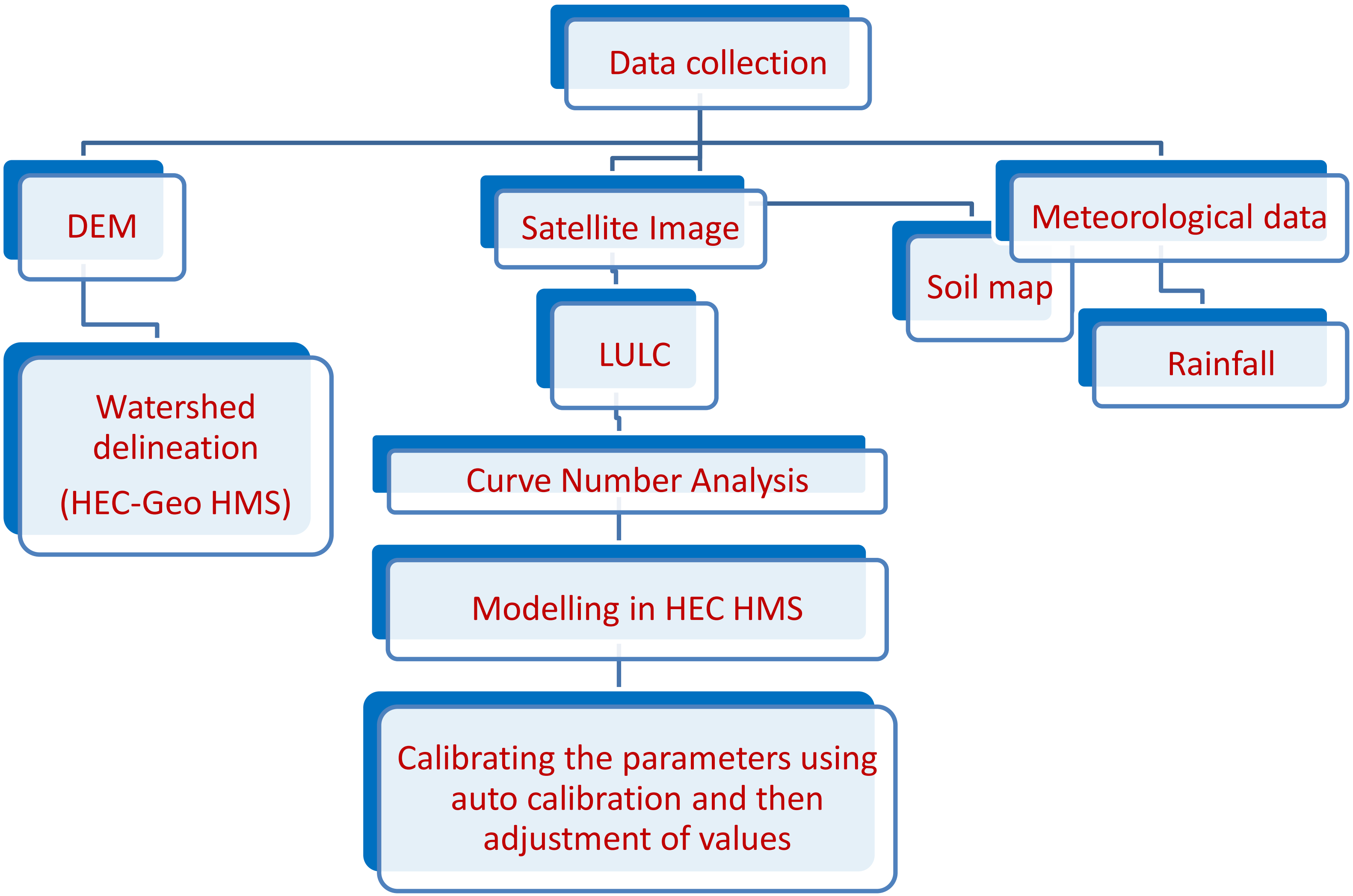
INPUT DATA USED FOR THE PRESENT STUDY

Data Type	Resolution	Source
Digital Elevation Model (DEM)	30m	Shuttle Radar Topography Mission (SRTM) http://www2.ipl.nasa.gov/srtm/
Soil	1km	FAO-UNESCO global soil map http:/www.fao.org/nr/land/soils/digital-soil-map-of-the-world/
Landuse Landcover	30m	LANDSAT 4-5 https://earthexplorer.usgs.gov/
Rainfall (IMD 2009-2012)	0.25° x 0.25° GRIDS	Indian Meteorological Department (IMD) http://www.imdpune.gov.in
Discharge (2009-2012)	Observed	Flood control cell http://210.212.135.230/fcc/

METHOD USED IN HYDROLOGICAL MODELLING USING HEC HMS

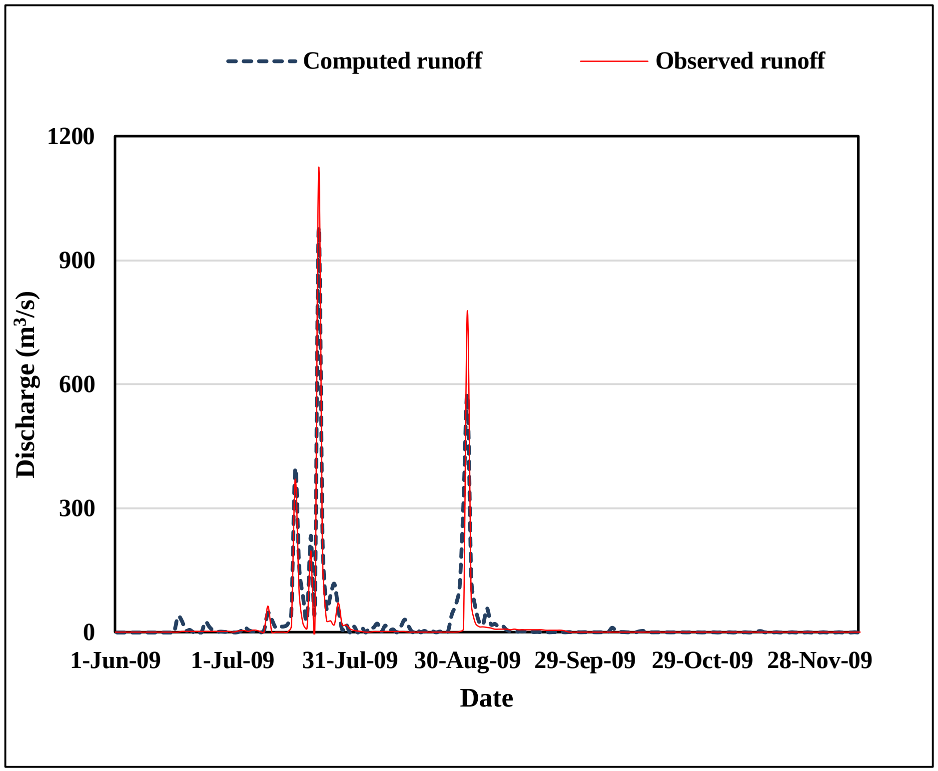
Loss method	• **SCS Curve Number**
➢**Transform method**	• **SCS unit hydrograph**
➢**Routing method**	• **Muskingum routing**
Base flow	• **None**
Software's used	• **ArcGIS 10.2** • **HEC-Geo HMS** • **HEC HMS 4.2.1**

METHODOLOGY ADOPTED FOR THE PRESENT STUDY



RESULTS AND DISCUSSION

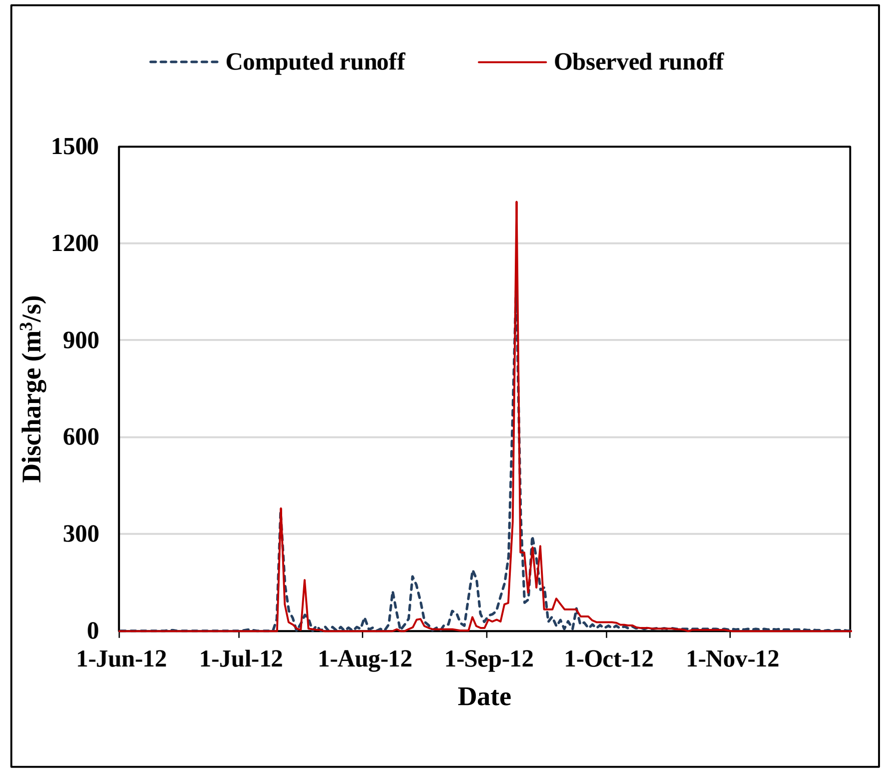
Calibration



2009 (Normal Year)

Observed peak discharge – 1124.8 m^3/sec
Computed peak discharge – 980 m^3/sec

Validation



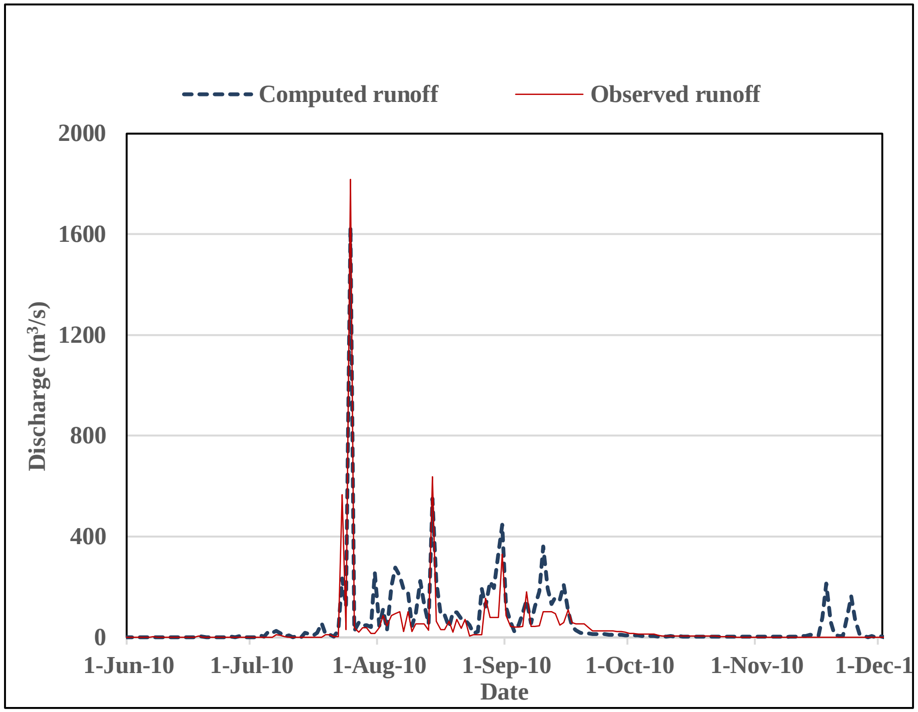
2012 (Normal Year)

Observed peak discharge 1012.6 m^3/sec
Computed peak discharge – 1329.2 m^3/sec

Comparison of simulated and observed peak discharge at Dharoi (Outlet

RESULTS AND DISCUSSION

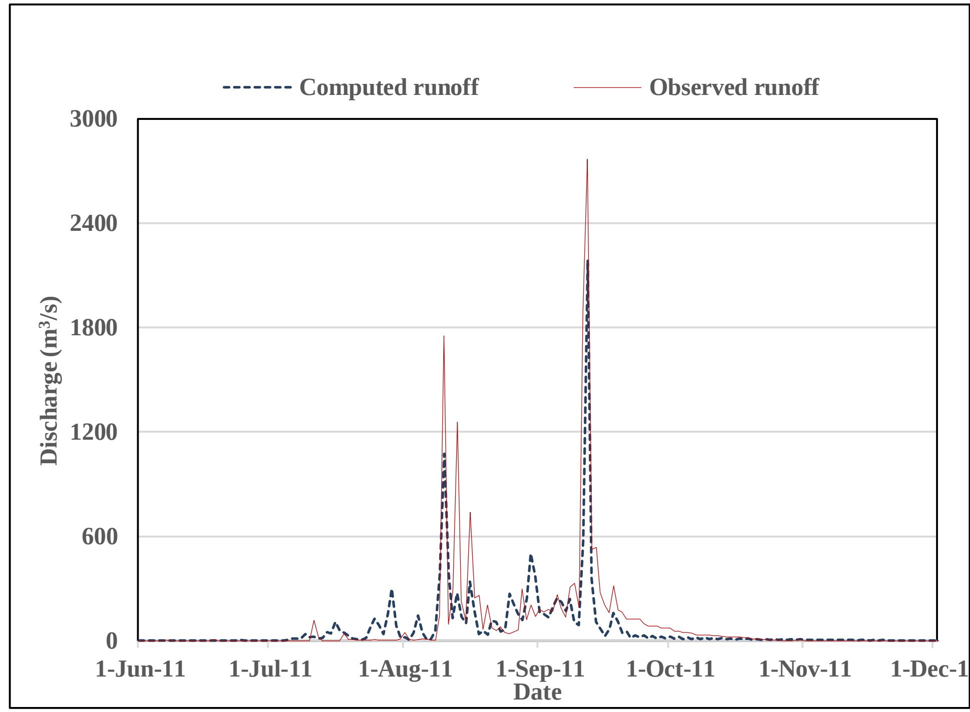
Calibration



2010 (Wet Year)

Observed peak discharge – 1817 m^3/sec
Computed peak discharge – 1628.3 m^3/sec

Validation



2011 (Wet Year)

Observed peak discharge – 2768.9 m^3/sec
Computed peak discharge – 2187.9 m^3/sec

Comparison of simulated and observed peak discharge at Dharoi (Outlet)

RESULTS AND DISCUSSIONS

Year	Meteorological condition	PERFORMANCE INDICES	
		R^2	NSE
2009 (Calibration)	Normal year	0.88	0.70
2012 (Validation)	Normal year	0.79	0.65
2010 (Calibration)	Wet year	0.72	0.65
2011 (Validation)	Wet year	0.76	0.55

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Thank You