Effect of Climate and Land Use/Cover Change on Spatial and Temporal Water Availability in Subarnrekha River Basin

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Introduction

- Climate Change → Global warming
  - Significant impacts on
    - Temperature
    - Precipitation

- More anthropogenic disturbances to natural settings
  - Increased LU/LC change activities
    - Reduction of forest cover
    - Increased agriculture
    - More industries
    - Reduced water spread area,
    - Second/indirec- increased atmospheric CO_2 concentration, etc.

Introduction

- Change in precipitation pattern
  - Excess water resources in some parts and scarcity elsewhere

- Water requirements of various sectors has increased

- It is necessary to evaluate
  - The extent of the changes and possible impacts on river basin scale water resources (Walker, 1991)

Objectives

To study the historic climate change and land use/land cover change pattern over the Subarnrekha river basin, (LU/LC- 2000 & 2008)

To calibrate and validate the Arc-SWAT hydrological model at different spatial scales for river basin using current LU/LC and climatic conditions, (cal. Jamshedpur)

To develop future expected land use change and collect downscaled (statistical and dynamical) climate change scenarios (AR5) for base period and compare them with observed period, (8 GCM models- DS & BC)

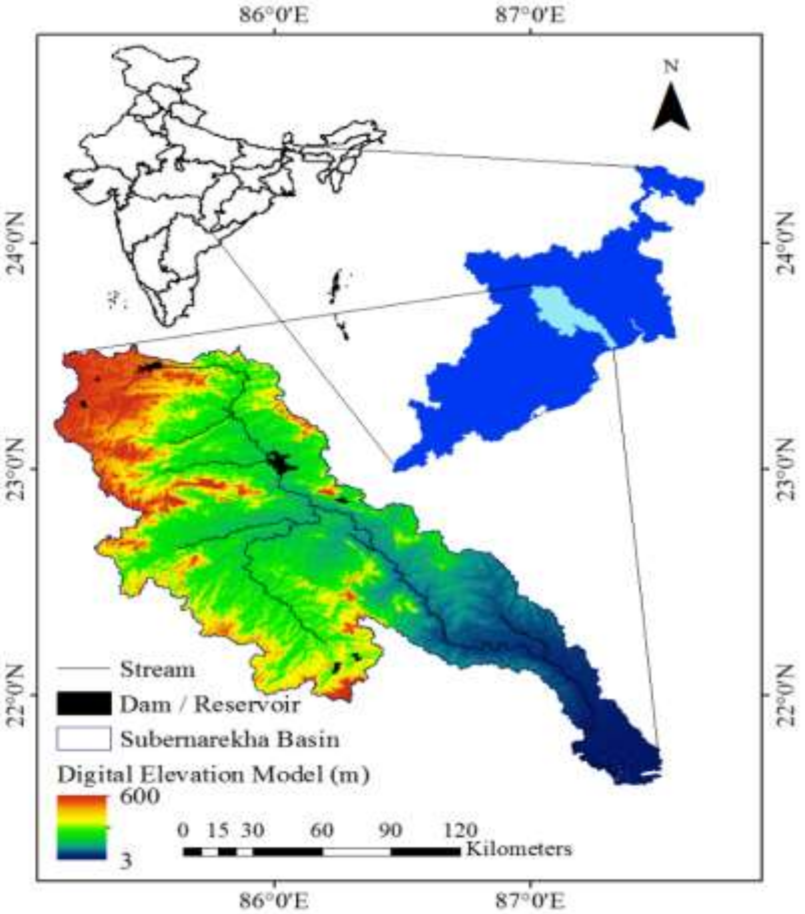
Objectives

To model spatial and temporal future water availability using downscaled climate and land use change scenarios to quantify the effect of climate and LU/LC change,

To quantify the uncertainty in modeling analysis arising from model parameters and input conditions,

To develop management scenarios to minimize impact of climate change on runoff and sediment yield under present and projected land cover changes.

Study Area: Subarnrekha River Basin



Index map of Subarnarekha river basin

Area : 19,121 km^2

Channel Length: ~395 km

Passes Through: Orissa, Jharkhand & West Bengal States

Jharkhand	~13,222 km^2
Odisha	~2,983 km^2
West Bengal	~3,022 km^2

Location:

Lat- 21°33´18´´N to 23°18´00´´N

Lon- 85°11´00´´E to 87°23´31´´E

Elevation: ~3m – 600m above MSL

Rainfall: ~1498.2 mm (annual average)

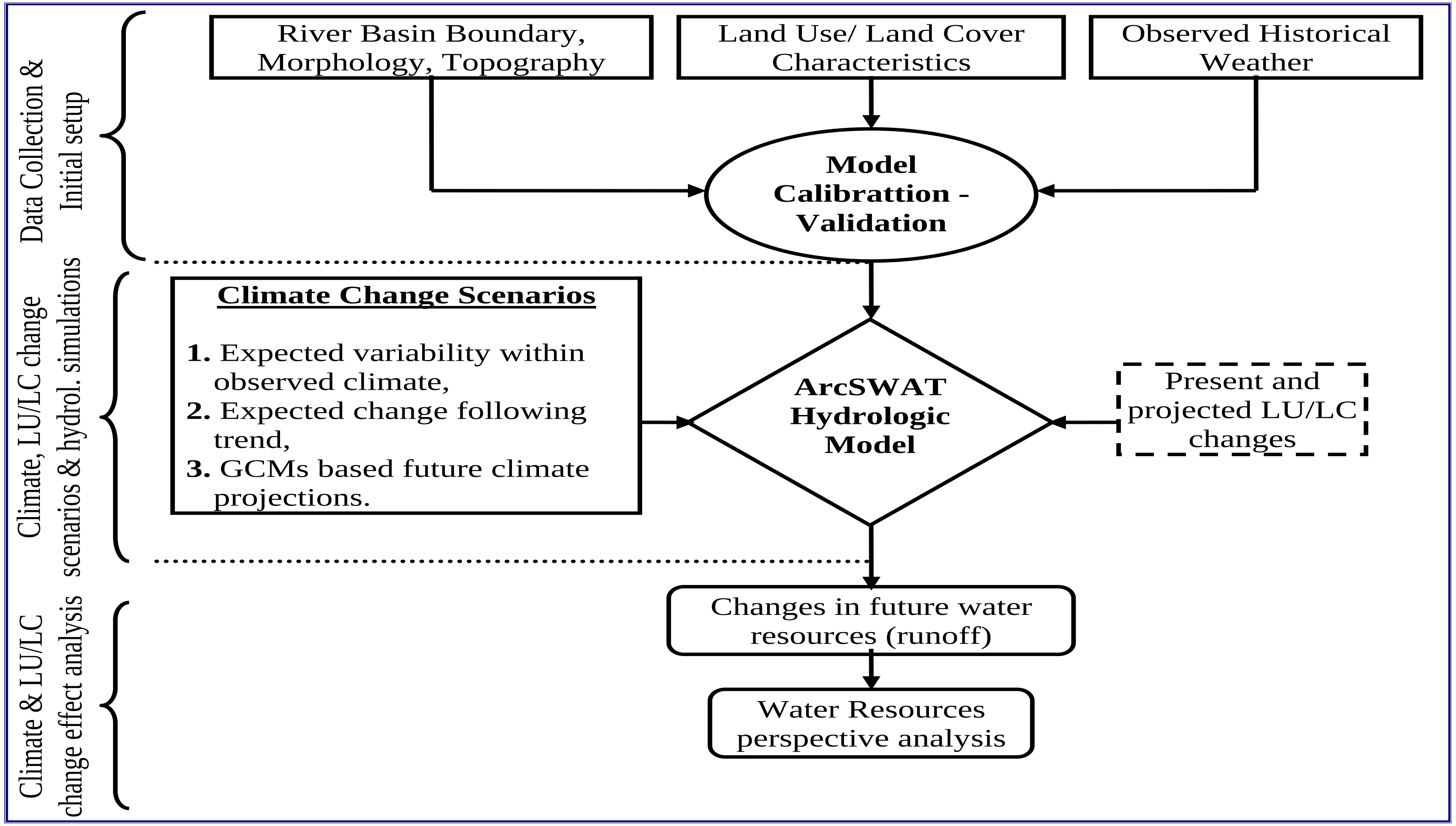
Temperature variation: ~10 °C to 45 °C

Relative humidity: ~45% to 92.21%

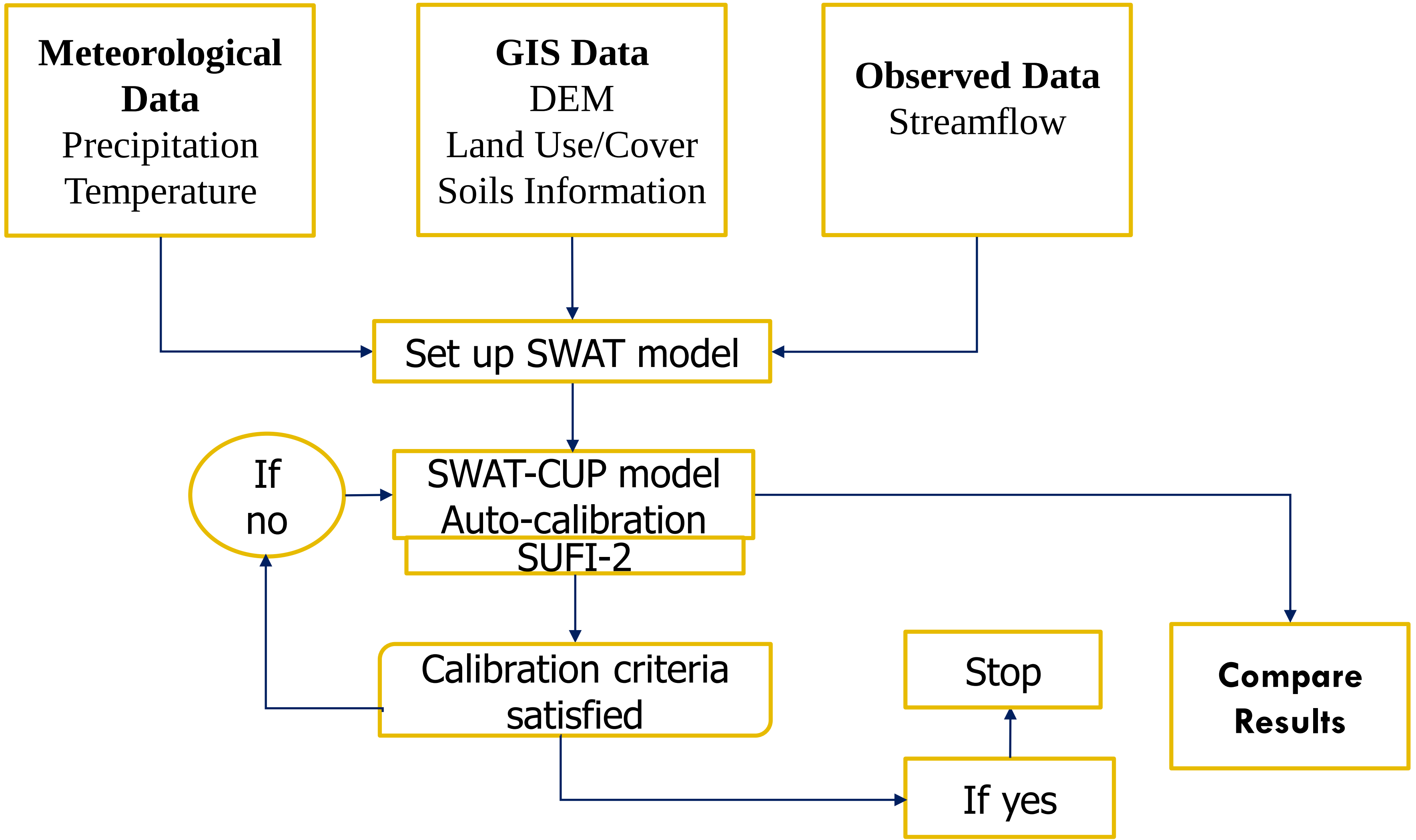
Data & Source

Data Type	Source	Data Description
DEM	Consultative Group for International Agriculture Research - Consortium for Spatial Information (CGIAR-CSI)	90 m x 90 m Resolution Digital Elevation Model
Soil Information	Food and Agriculture Organization of United Nations (FAO)	Soil classes and physical properties
Land Use / cover Data	Global Land Cover Facility (GLCF) (http://glcf.umiacs.umd.edu)	Landsat images (Landsat ETM^{+}), Land use classification (8 classes)
Hydro-met. Data	India Meteorological Department (IMD), Central Water Commission (CWC), Bhuvaneswar	Daily rainfall, maximum and minimum temperature for the period 1987 to 2014, and daily streamflow data 1987-2014
Topographic Maps	University of Texas Libraries. (http://www.lib.utexas.edu)	Topography of the river basin

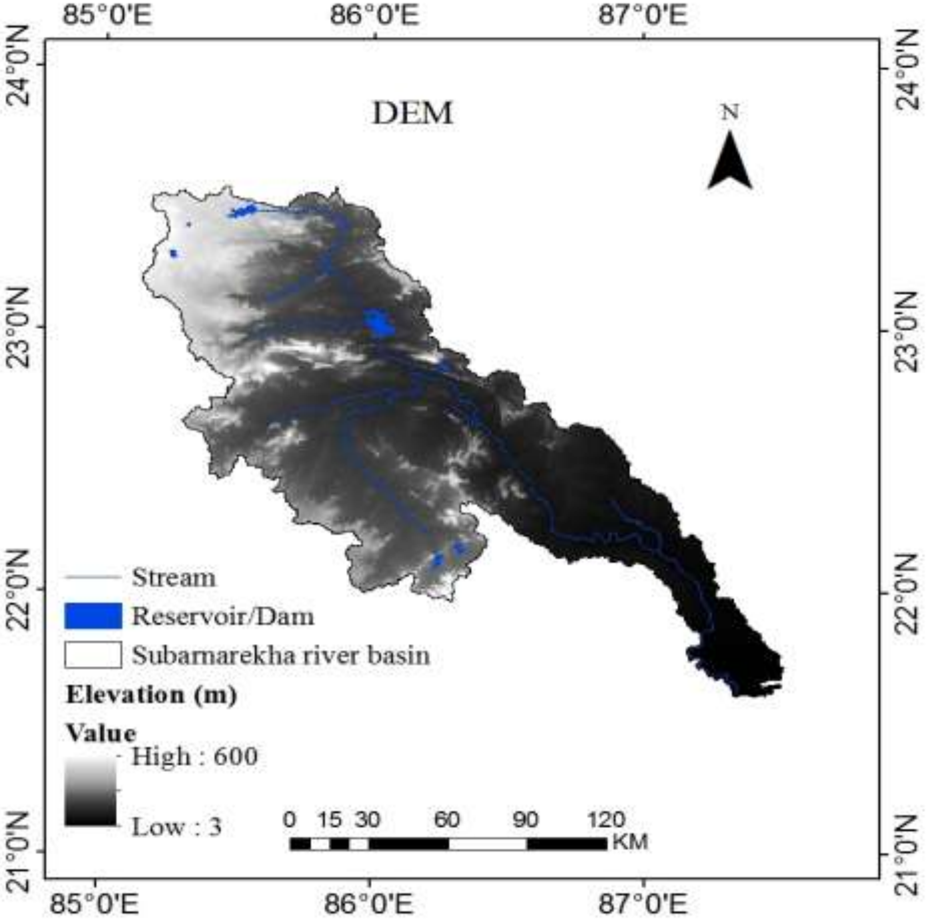
The Schematic of the Study

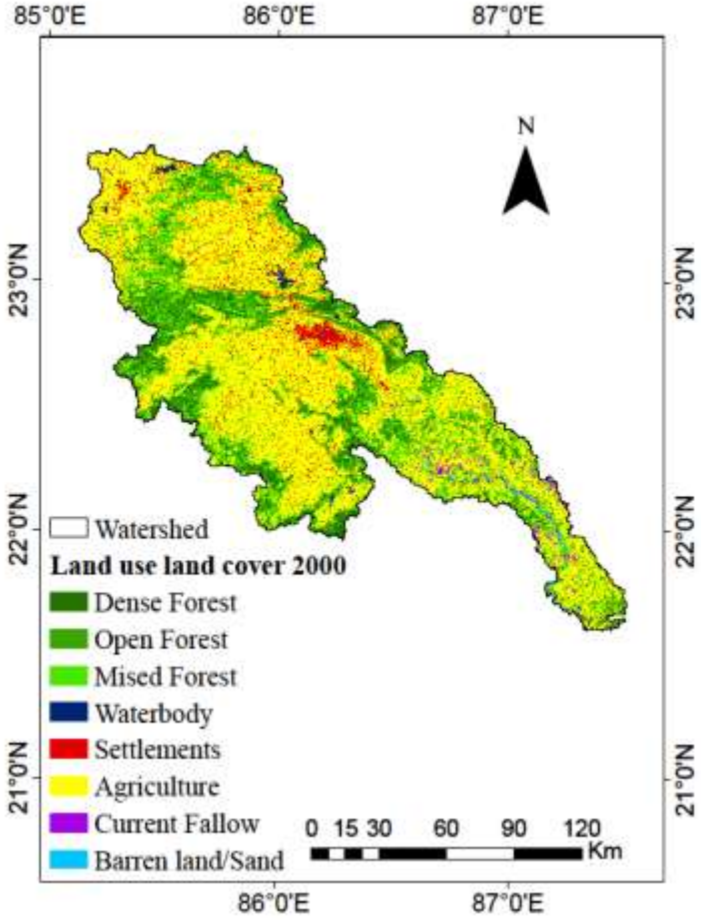


Methodology- Work Done



Methodology- DEM and Land Use/Cover

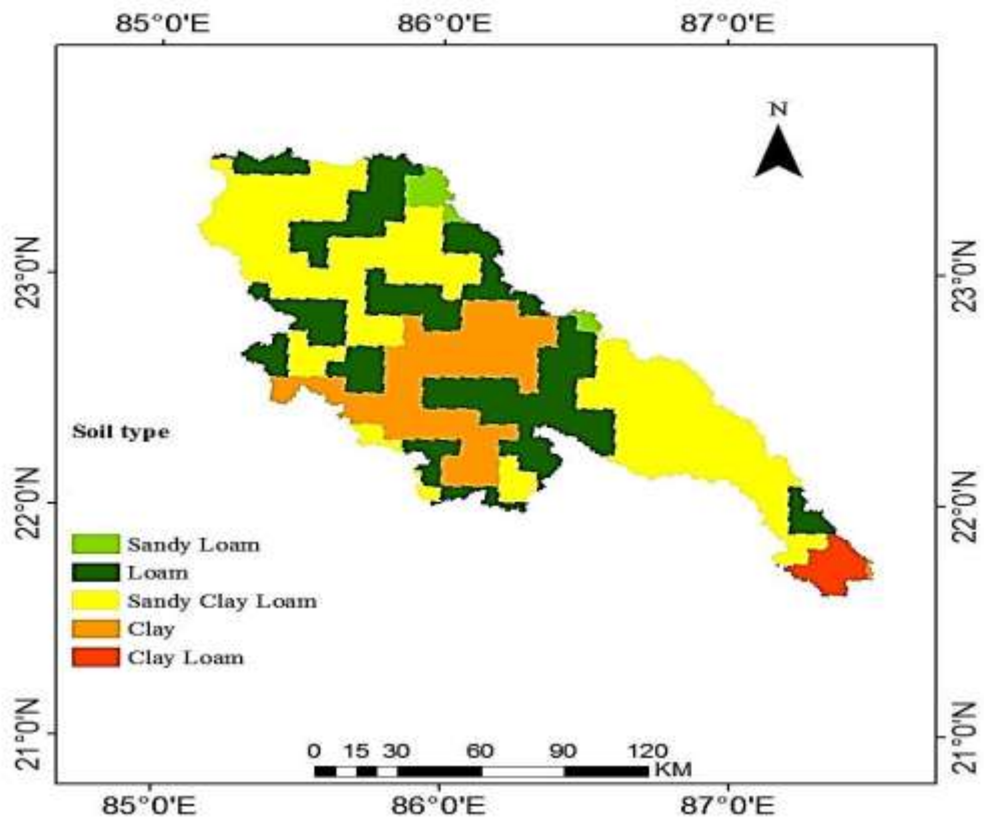




LU/LC	2000	2008
Df- *dense forest*	7.14	6.17
Of- *open forest*	11.38	7.89
Mf- *mixed forest*	18.74	18.20
Wt- *waterbody*	0.80	0.91
Set - *settlement*	6.25	6.89
Ag - *agriculture*	54.00	57.70
Cf- *current fallow*	1.34	1.84
Br / Sd - *barren land / sand*	0.34	0.40

DEM and LULC map (of 2000) of Subarnrekha river basin

Methodology- Soils

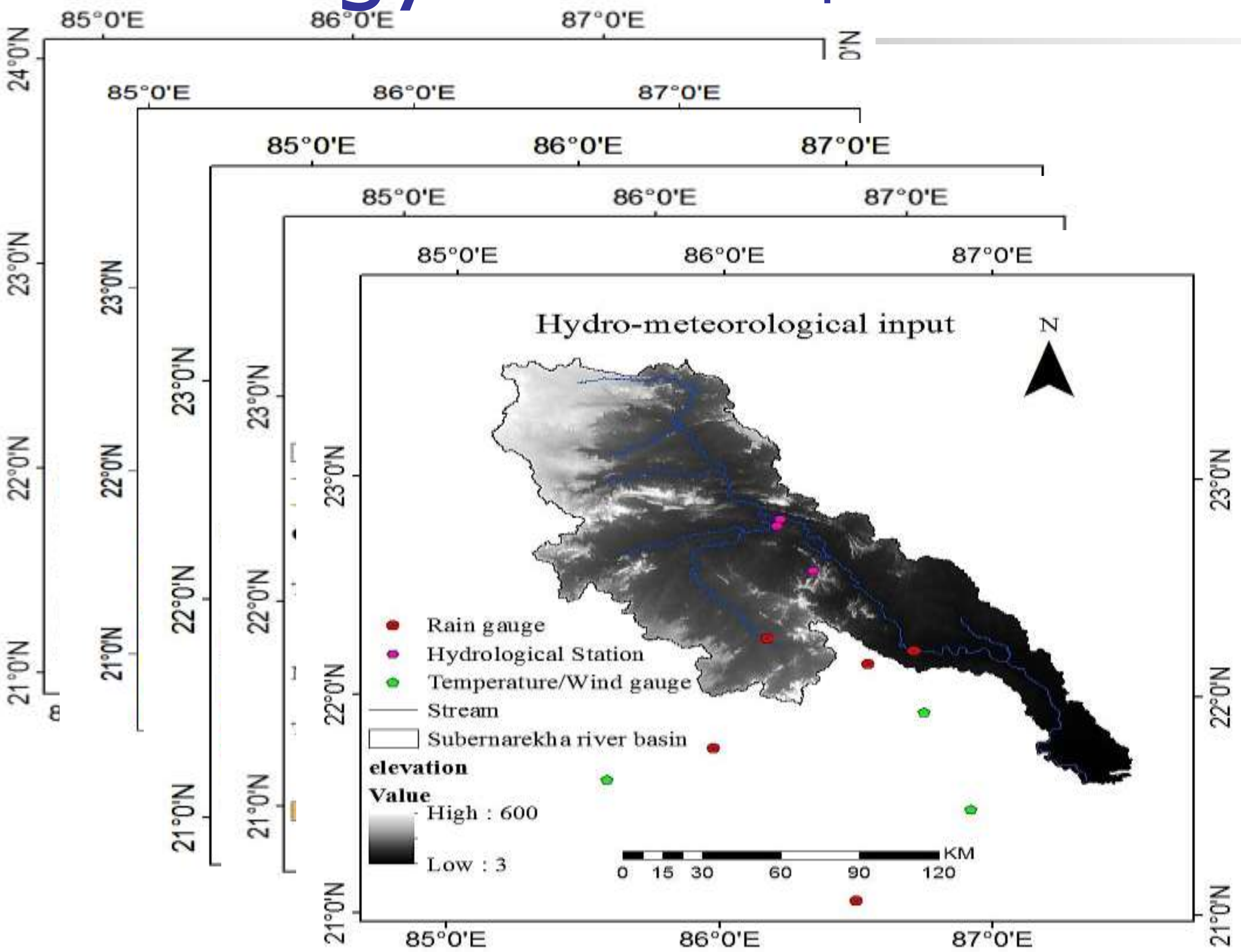


Soil map of Subarnarekha river basin

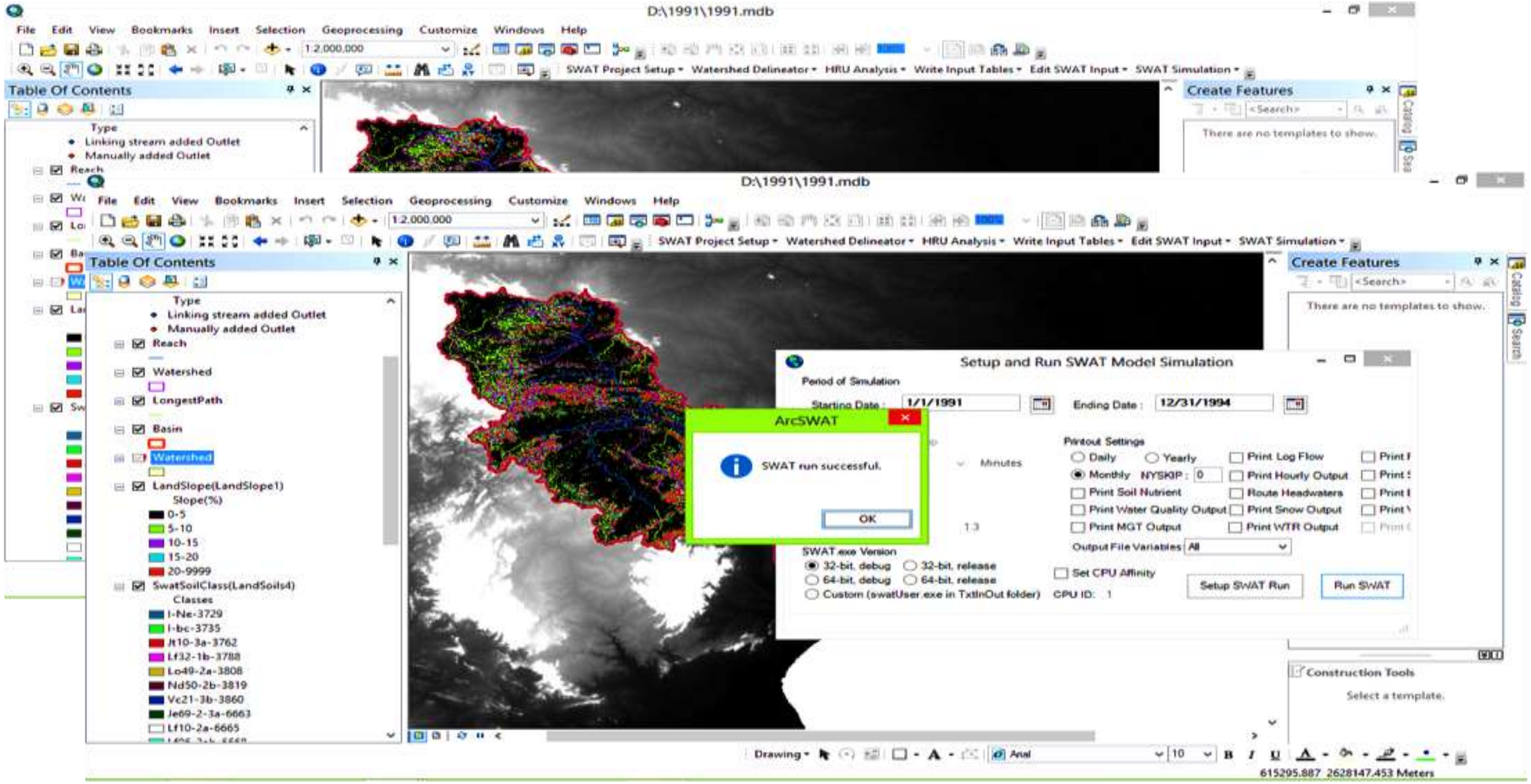
Details of soil types in the Subarnarekha river basin

Soil type	% Basin area	Hydrological Soil Group
Sandy clay loam	43.70	C
Loam	33.32	C
Clay	18.42	D
Clay loam	2.67	C
Sandy loam	1.89	C

Methodology- SWAT Setup



Methodology- SWAT Model Run



Methodology- Model Performance Evaluation

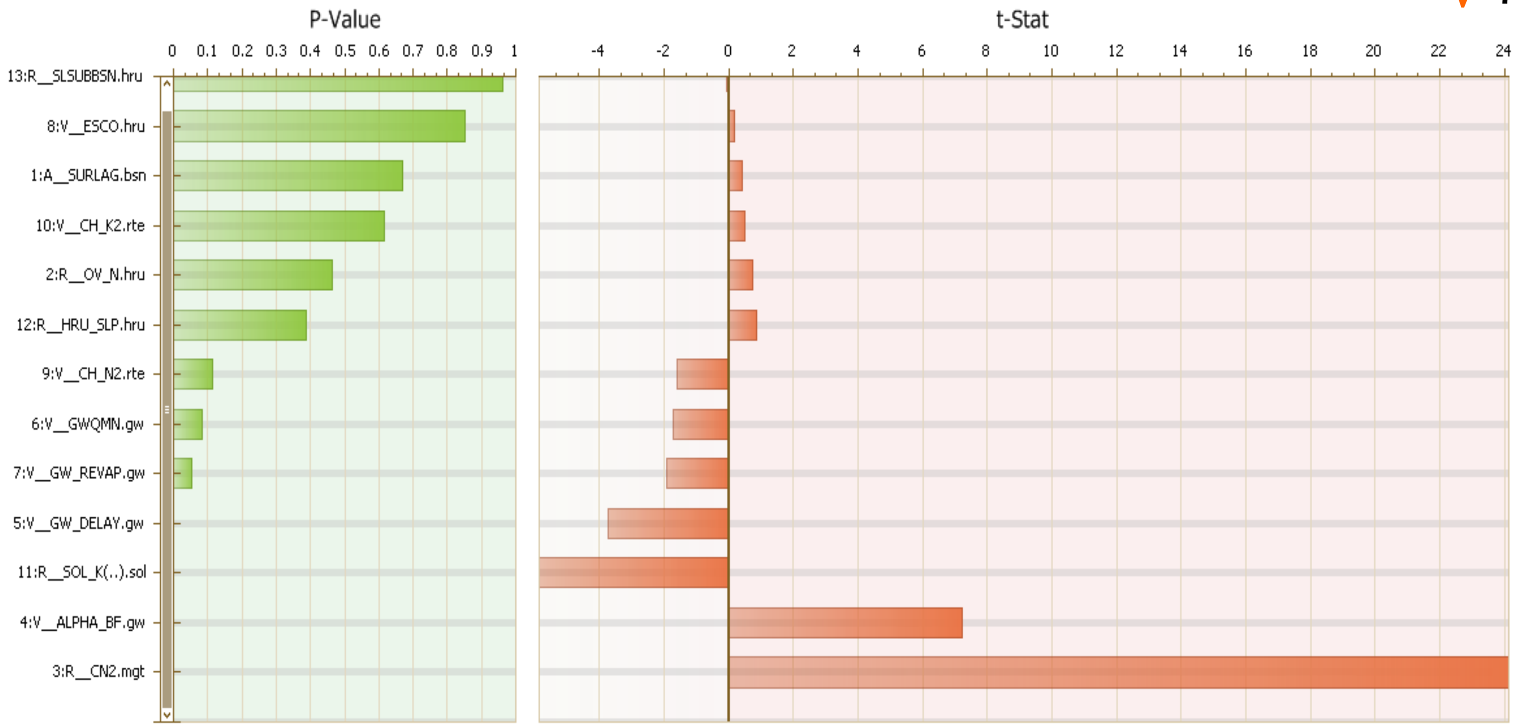
Coefficient Of Determination (R^2) : Degree of co-linearity between simulated and measured data, >0.5 – acceptable.

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (O_i - O_{avg})(S_i - S_{avg})}{\sqrt{\sum_{i=1}^{n} (O_i - O_{avg})^2} \sqrt{\sum_{i=1}^{n} (S_i - S_{avg})^2}} \right\}^2$$

Nash-Sutcliffe Efficiency (NSE) : How well the observed versus simulated data fits to 1:1 line, 1-optimal value.

$$NSE = 1 - \left\{ \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2} \right\}$$

Results- Sensitivity Analysis of SWAT Setup

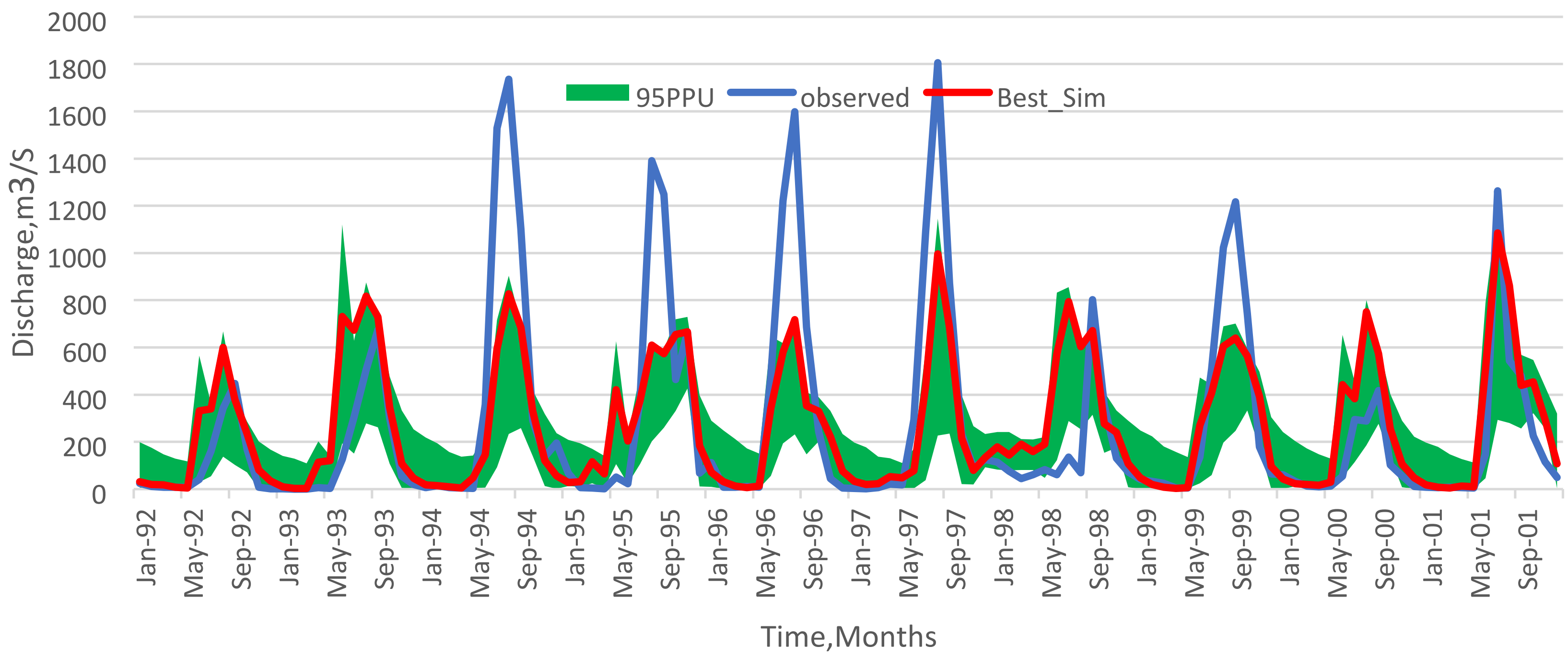


√ 13 parameters considered for calibration,

√ 7 were found to be most sensitive -

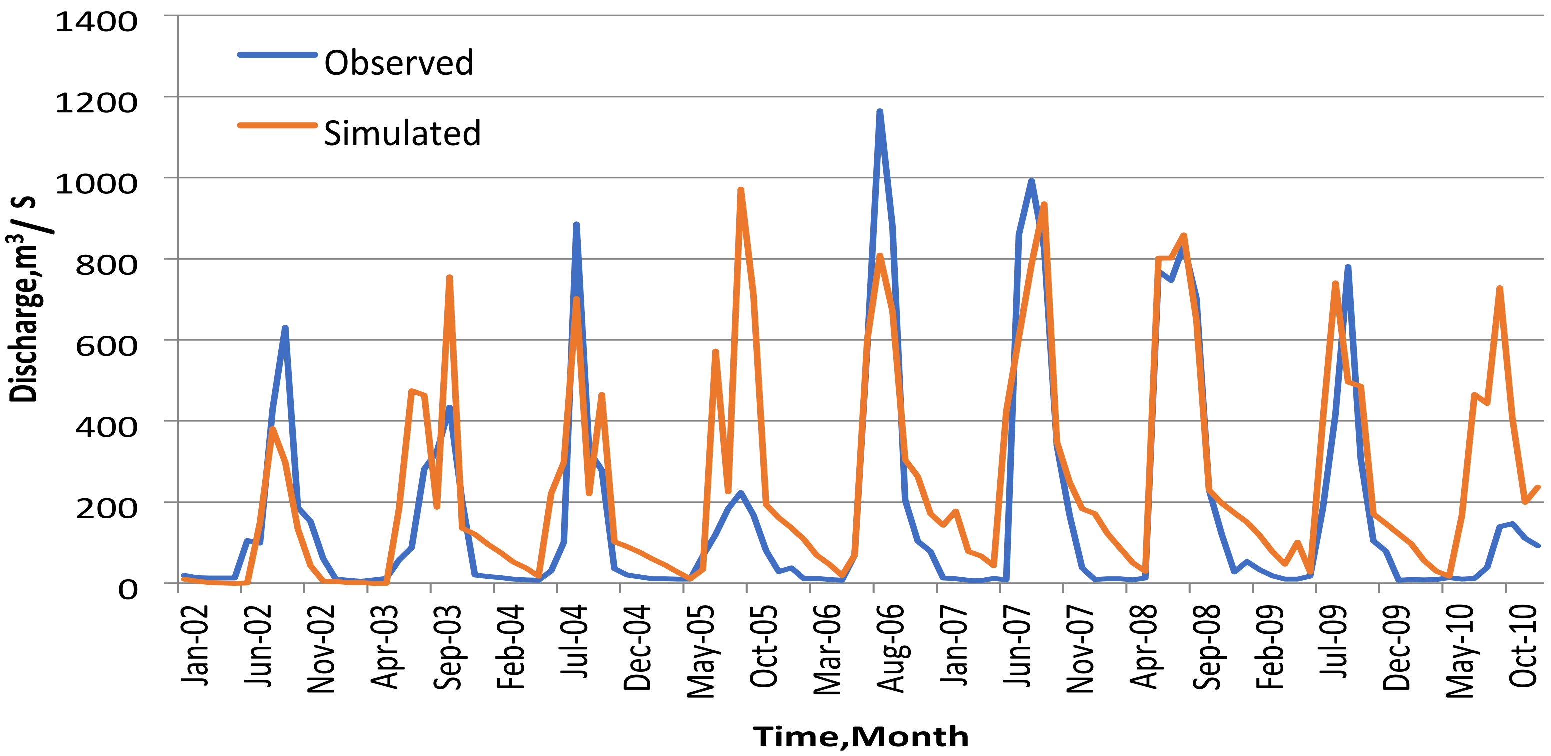
- soil evaporation compensation factor,
- threshold depth of water in the shallow aquifer for return flow to occur,
- SCS runoff CN for AMC-II,
- base flow alpha factor,
- average slope steepness,
- Manning's 'n' for overland flow, and
- surface runoff lag coefficient.

Results- Model Calibration



Monthly observed and simulated streamflow, and 95PPU at Jamshedpur gauging station during calibration period (1992-2001)

Results- Model Validation



Monthly observed flow, simulated flow at Jamshedpur during validation period (2002-2010)

Results- Model Calibration & Validation Statistics

Statistical performance of model simulations during calibration and validation period at Jamshedpur gauging station

Statistical Parameter	Streamflow (Monthly)	
	Calibration	Validation
Nash-Sutcliffe Coefficient (E_{NS})	0.56	0.52
Coefficient Of Determination (R^2)	0.58	0.60
PBIAS (%)	1.10	23.80

- Monthly Results indicate quite satisfactory performance for monthly time step [Moriasi et al. (2007)] ,
- **There is scope for refinement of the model parameterization to improve the modelling results.**

Work Progress

Land Use/Cover- Satellite Data Availability

Year	Satellite/Sensor	Spatial Resolution (m)	Path/Row	Acquisition Date
1987	Landsat TM	30	139/44,139/45 140/44,140/45	15 December 1987 06 December 1987
1991	Landsat TM	30	139/44,139/45 140/44,140/45	08 January 1991 31 January 1991
1995	Landsat TM	30	139/44,139/45 140/44,140/45	19 January 1995 11 February 1995
2000	Landsat ETM^+	30	139/44,139/45 140/44,140/45	10 December 2000 17 December 2000
2004	Landsat TM	30	139/44,139/45 140/44,140/45	13 December 2004 04 December 2004
2008	Landsat TM	30	139/44,139/45 140/44,140/45	08 December 2008 15 December 2008

Work Progress

Climate Data- GCMs & Resolution

GCM		Country	Resolution
NorESM1_M	NE	Norway	1.8947° × 2.5°
MIROC5	M5	Japan	1.4008° × 1.40625°
MRI_CGCM3	MG	japan	1.12148° × 1.125°
BCC_CSM1_1_M	BC	China	2.7906° × 2.8125°
MIROC_ESM	ME	Japan	2.7906° × 2.8125°
GFDL_CM3	GC	USA	2.0° × 2.5°
MIROC_ESM_CHEM	MC	Japan	2.7906° × 2.8125°
IPSL_CM5A_LR	IL	France	1.8947° × 3.75°

- 8 GCMs, covering all India
- Collection period:
  - 1950-2005 (baseline period)
  - 2006-2099 (Future scenarios)

    RCPs- 2.6, 4.6, 6.0, 8.5

Downscaling and Bias correction of GCM Outputs

- √ Downscaling-
  - ➢ Bi-linear interpolation method – to scale down to 0.25° x 0.25°

- √ Bias correction-
  - ➢ By mapping CDFs of model data to the CDF of observed data-

$$y_{his} = F_{obs}^{-1}\left(F_{\mathrm{mod},hist}\left(x\right)\right)$$

  - ➢ Future data correction- correcting data 1st with-respect-to model historical condition then *wrt* observations-

$$y_{fut} = F_{obs}^{-1}\left(F\left(x_{sce}\right)_{control}\right)$$

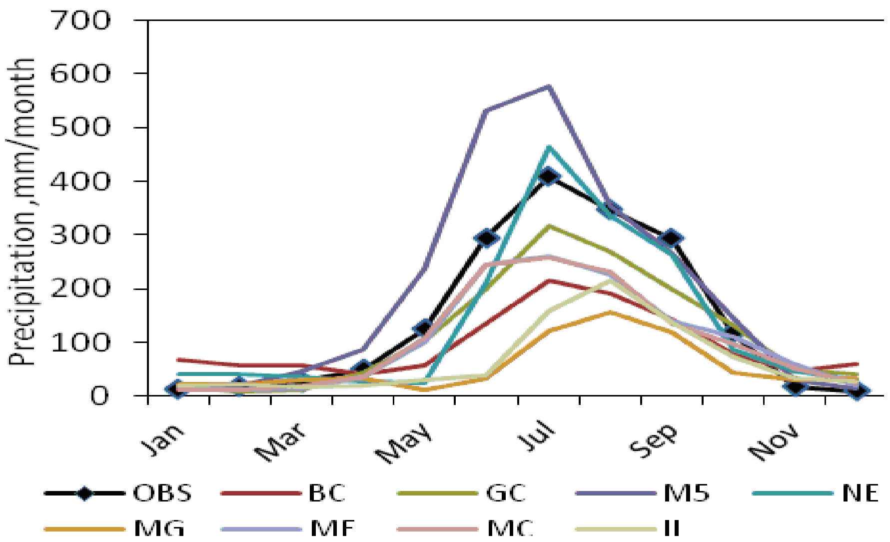
Biases … Correction Methods

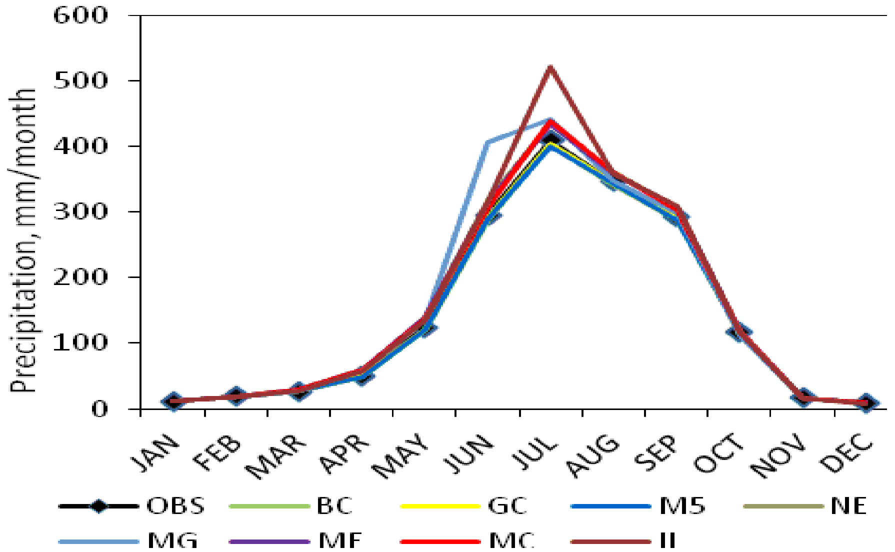
Variable	Method	Function
Rainfall	Gamma distribution (Thom, 1958)	$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}$
Temperature (min. & max.)	Gaussian distribution (Cramer, 1999	$f(x) = \frac{1}{\sigma\sqrt{2\Pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$

Biases … Rainfall & Solar Radiation

- Bias correction of GCM outputs have been performed for historical period (1976-2005) ,
- Bias correction improved the model outputs for historical period.

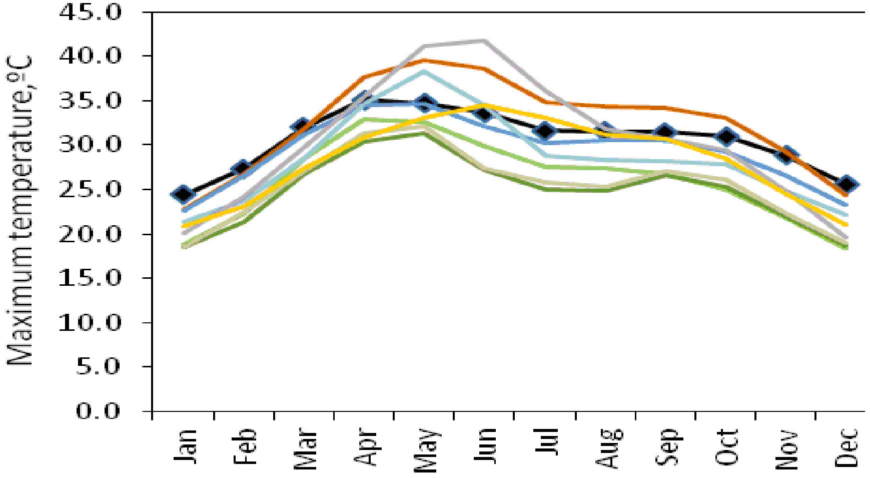
Monthly-mean Rainfall

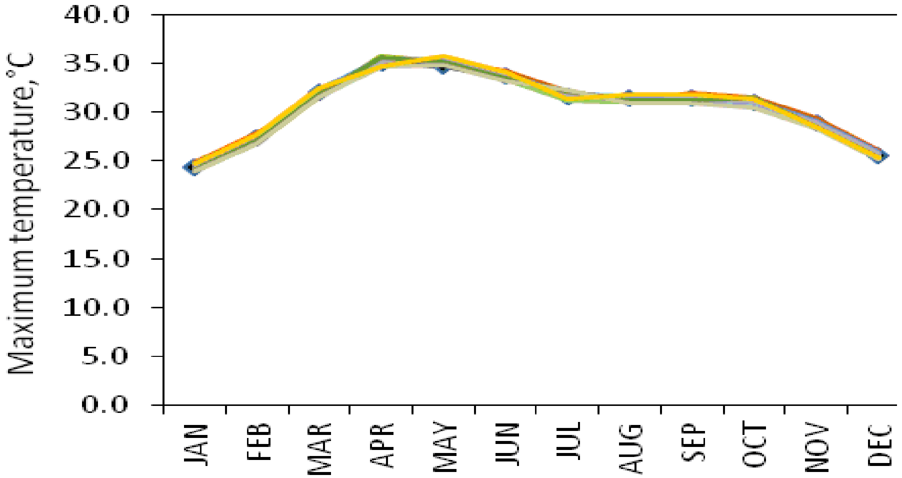




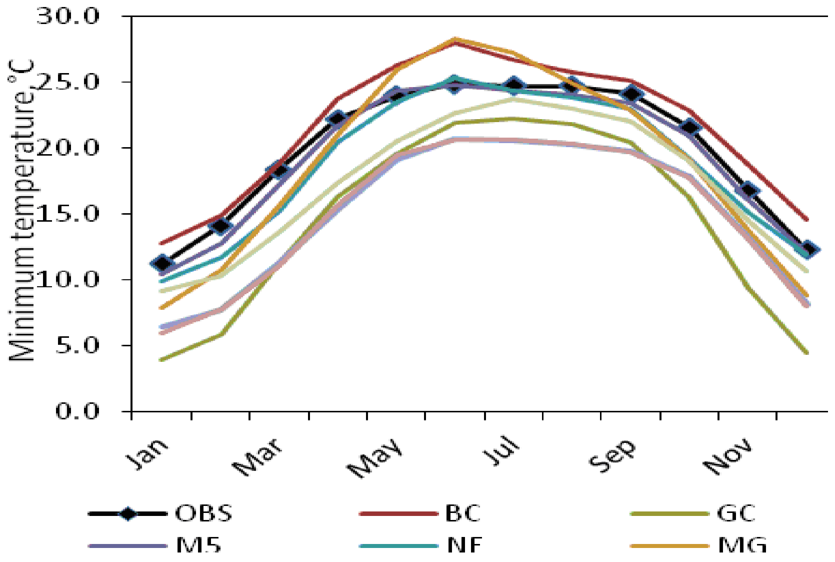
Biases … Temperature (min. & max.)

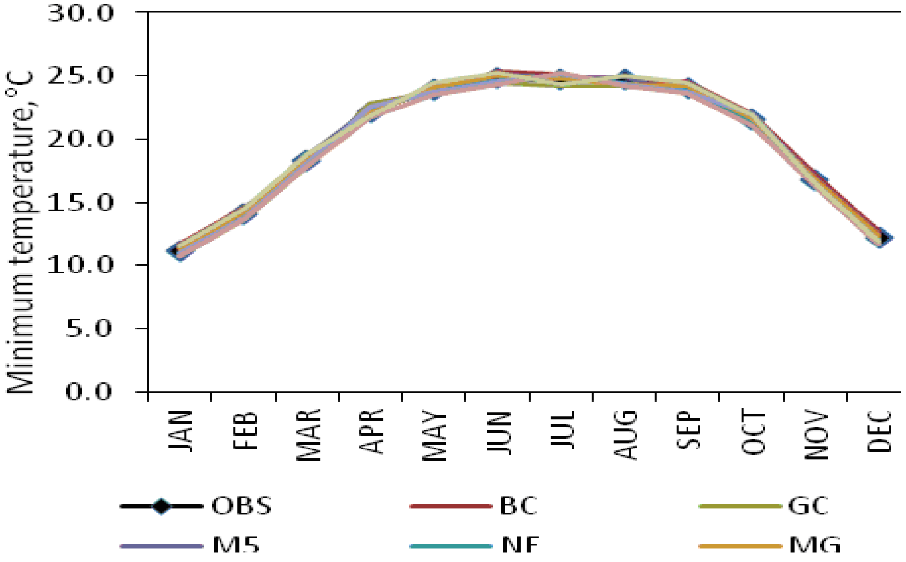
Monthly-mean Max. Temp.





Monthly-mean Min. Temp.





Work Progress

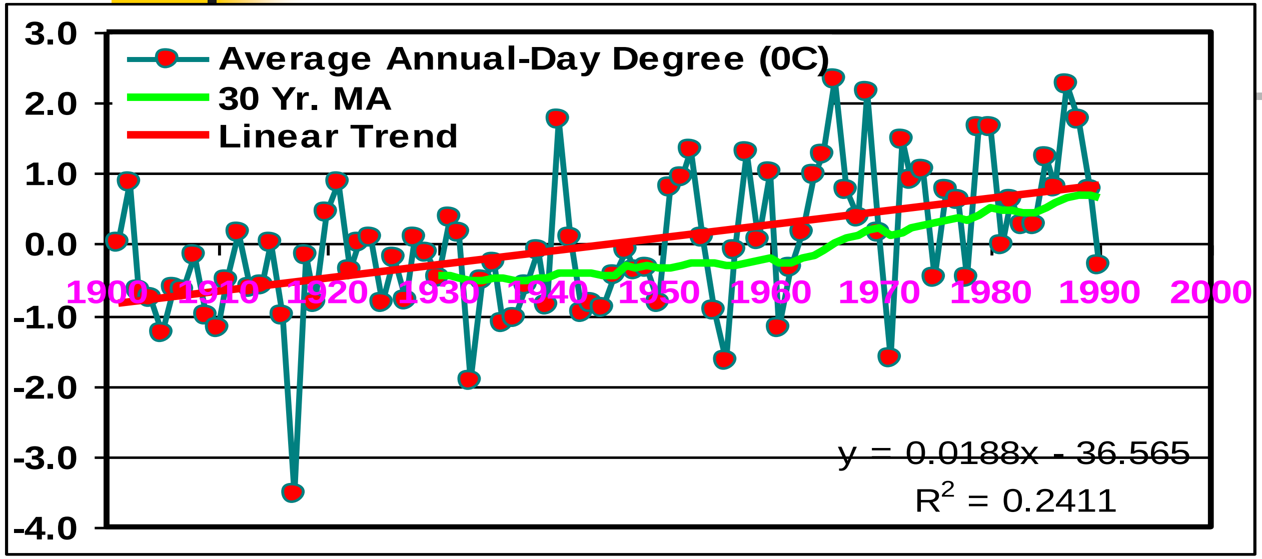
Sl. No.	Particular	Time Schedule (Months from Start)	Remark
1.	Initial arrangements (SRF, Computer, Software)	03	Adv. SRF Position
2.	Data collection (Soil, morphologic and LU/LC)	09	Completed
3.	Meteorological and hydrological data collection	12	Completed..
4.	Data analysis, CC land LU/LC change scenario generation, collection GCM outputs	18	Going on
5.	ArcSWAT setup, calibration, validation and scenario runs	18	Going on
6.	Developing relationship between water resources, climate and LU/LC	24	-
7.	Analysis of the results and uncertainty analysis for water resources study	30	-
8.	Scenario runs for resources management	33	-
9.	Documentation and Report Preparation	36	-

Questions?... Suggestions?

Thank you for your attention

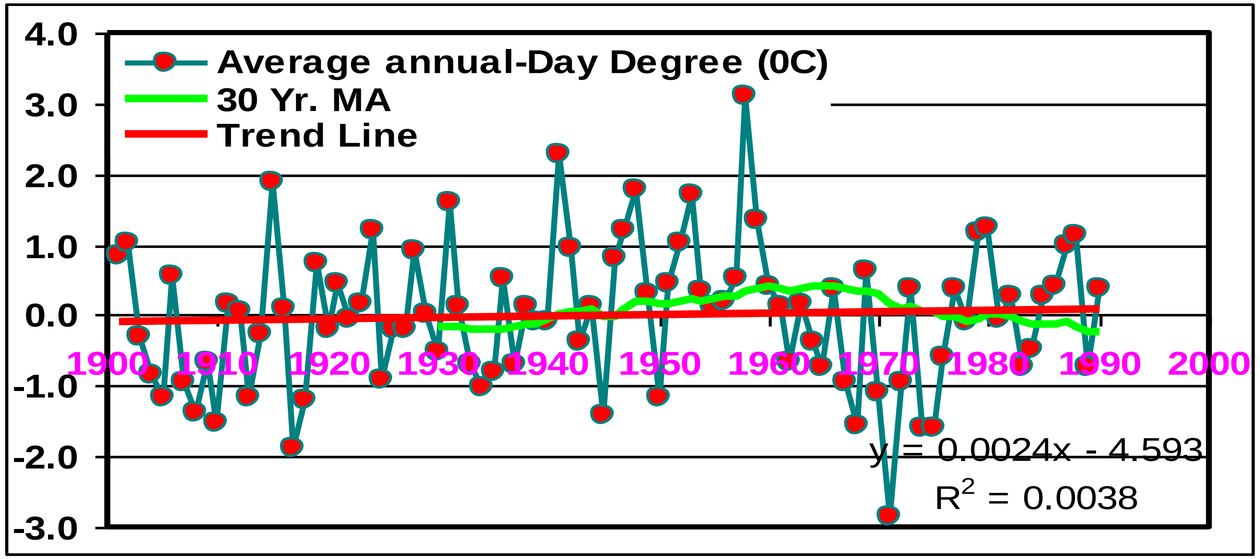
Global Warming

Increased Maximum & Minimum Temperature



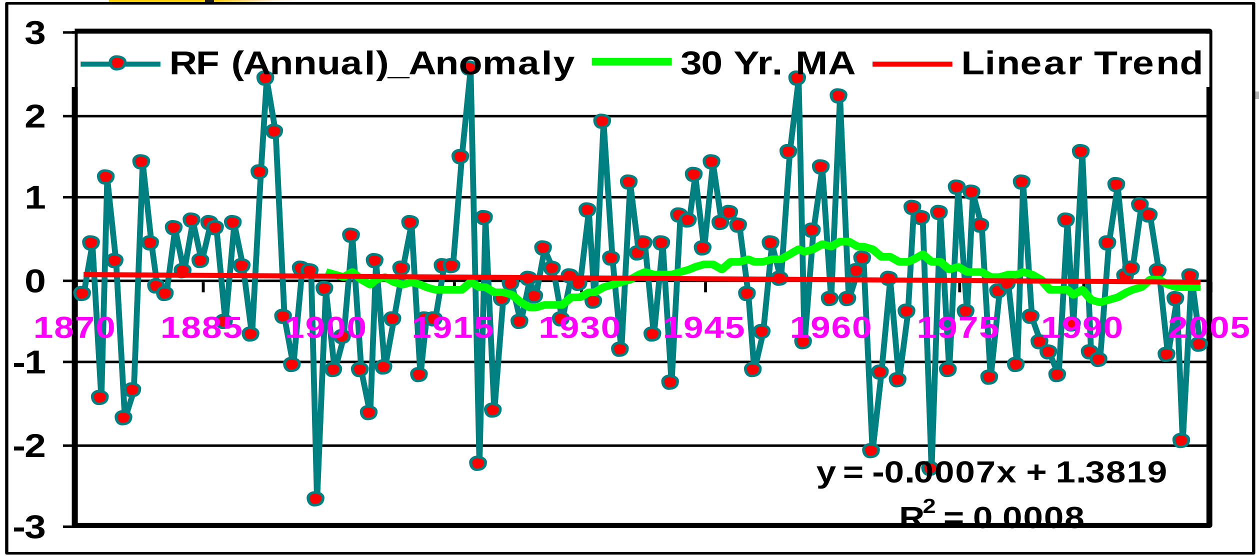
- Significant increase in average annual-day degree maximum temperature,
- Changed about 0.5 °C in last 90 years with highest variation about 2 °C.

- Increase in average annual-day degree minimum temperature,
- Highest variation in last 90 years is about 1.5 °C.



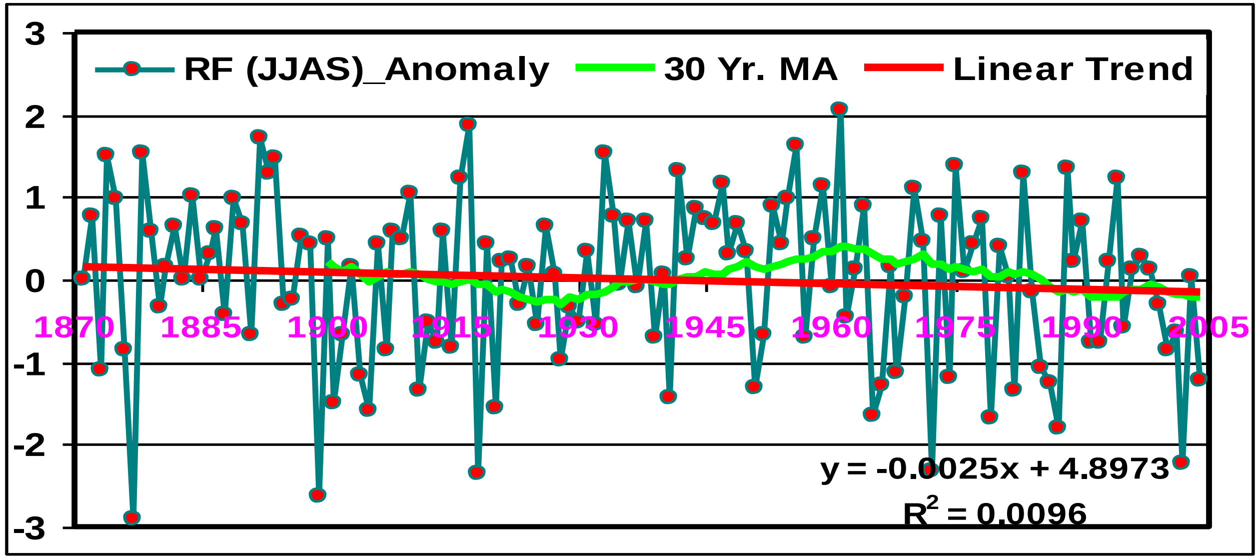
Global Warming

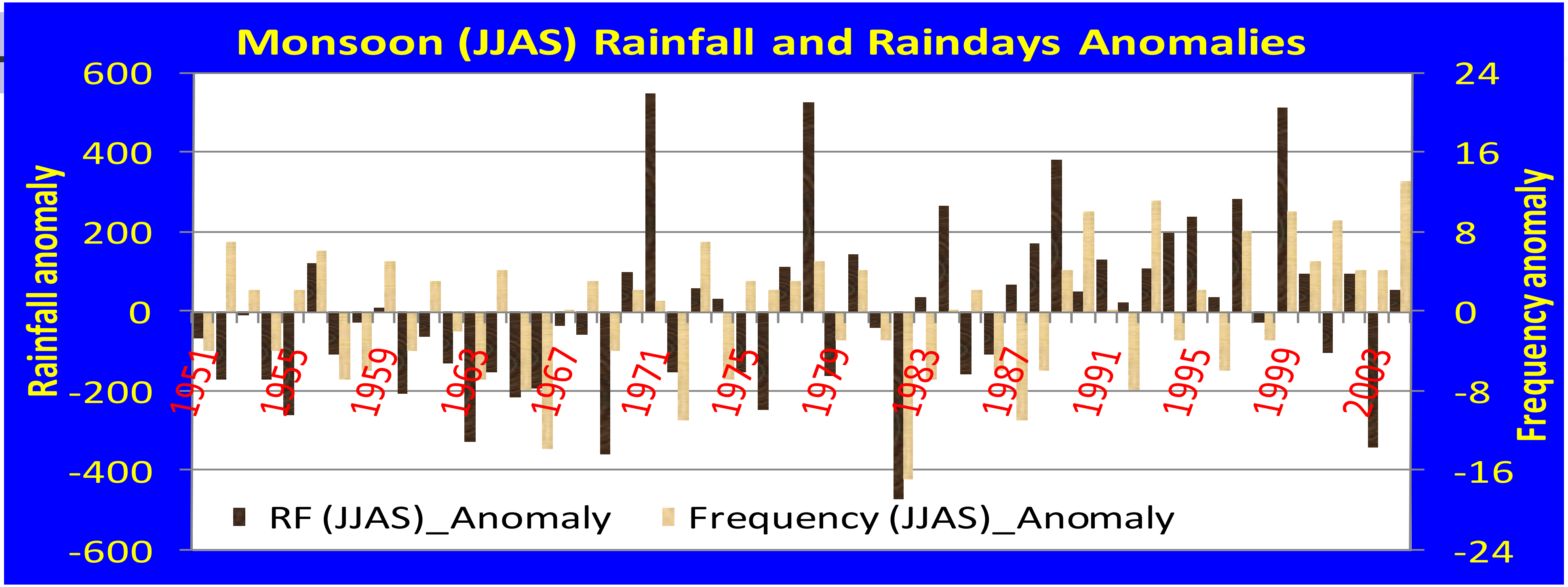
Changes in Annual/Seasonal (JJAS) Rainfall



- Reducing average annual rainfall of India,
- Reducing average seasonal-monsoon (JJAS) rainfall of India,
- Seasonal reduction in monsoon rainfall is prominent than annual

- Annual and seasonal reduction may have influential changes in rainfall frequency and intensities.





- Rainfall Frequency- No. of raindays in particular time (Annual and seasonal)

Interpretation keys used for LULC mapping

LULC	Tone/ Colour	Texture	Shape	Description
Df	Dark red	Rough	Irregular	Area with more than 40% canopy density
Of	Light red	Rough	Irregular	Area with 10–40% canopy density
Mf	Bright red/brown	Rough	Irregular	Area with less than 10% canopy density and commercial timber production
Set	Cyan blue	Medium	Irregular	Urbanized area
Wt	Deep /light blue	Smooth	Irregular	River, reservoir, pond, tank
Ag	Bright Green	Smooth	Regular	Area under crop cultivation
Cf	Whitish/grayish	Smooth	Varying	Area with sparse or no vegetation
Br / Sd	White	Smooth	Irregular	River bed areas