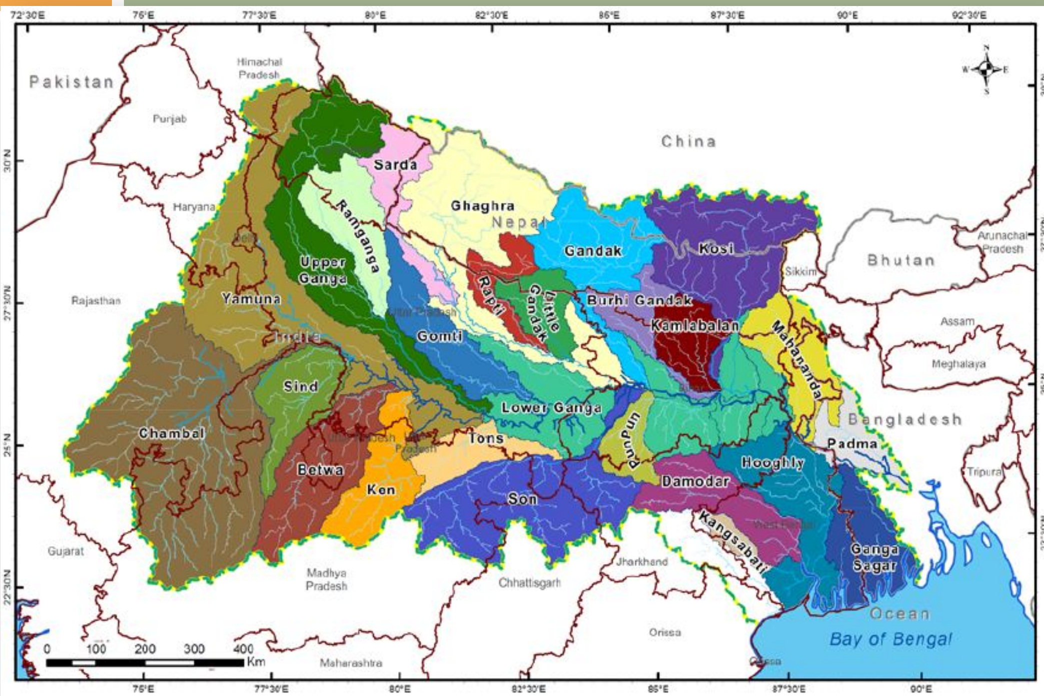
GLACIER AND SNOWMELT MODELLING USING SWAT: GANGA BASIN CASE STUDY

INRM Consultants Pvt. Ltd.

Introduction

- *Snowmelt Runoff contribution in the Himalayan Rivers*
- *Estimation of Average contribution of Snowmelt Runoff*
- *Snow contribution to Stream Runoff in the Ganga River Basin*
- *Calibrated snowmelt parameters*
- *Validation at a few Global Runoff Data Centre (GRDC) gauge sites.*

Ganga Basin SWAT Hydrological Modelling - Details

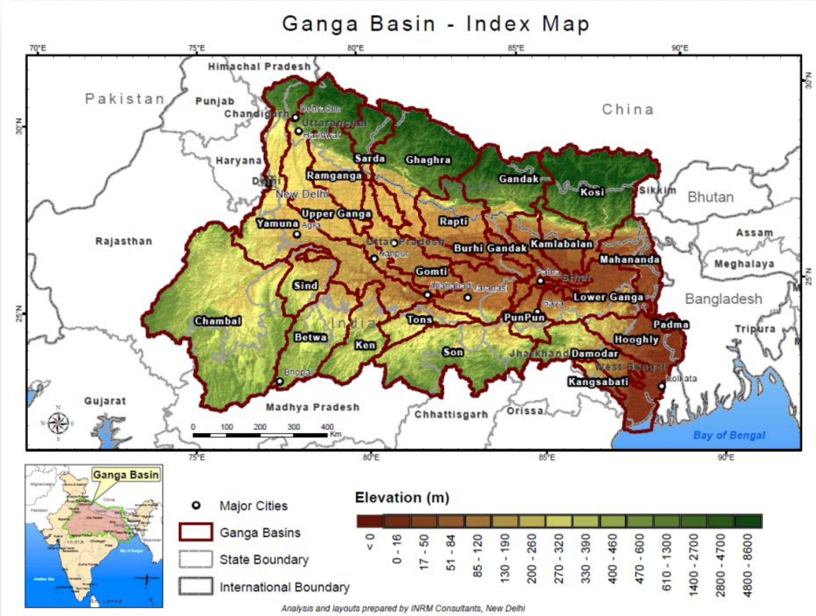


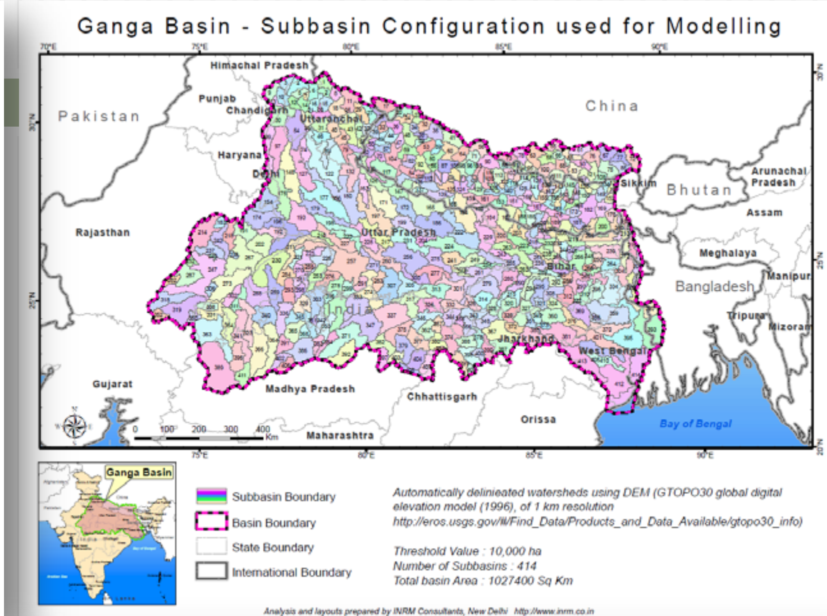
- **Tools used**
  - Modelling: SWAT (Soil and Water Assessment Tool)
- **Data used**
  - ***Digital Elevation Model***: GTOPO30 global digital elevation model (1996), of 1 km resolution
  - ***Land use***: IWMI_IRRSO, 500 m (IWMI – Irrigated area by source/Landuse merge)
  - ***Soil***: FAO Global data, 1:5M
  - ***Drainage***: Hydroshed,1:250,000
  - ***Weather***:
    - WATCH Reanalysis weather data (1965–2001)
    - Climate Change: PRECIS RCM: IPCC SRES A1B scenario
  - ***GRDC Observed discharges***

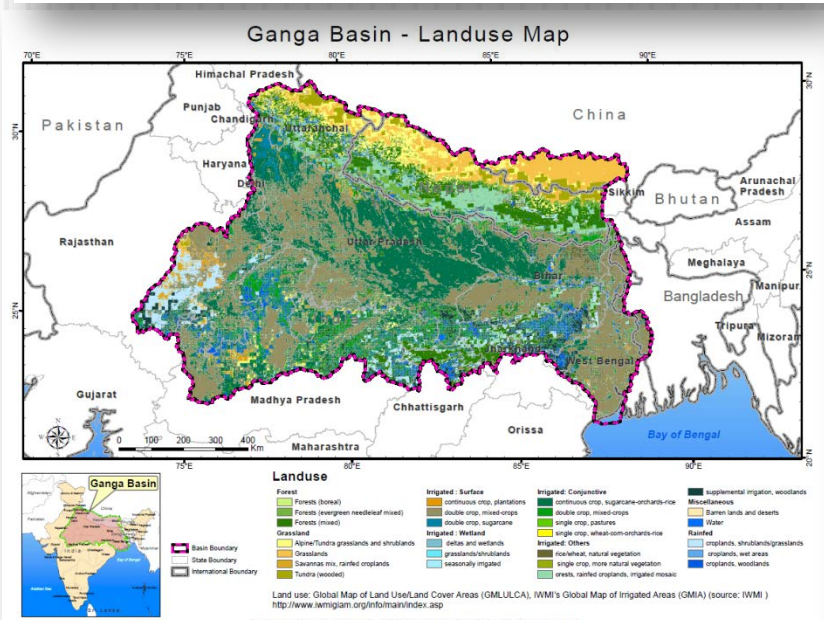
This work was supported by :

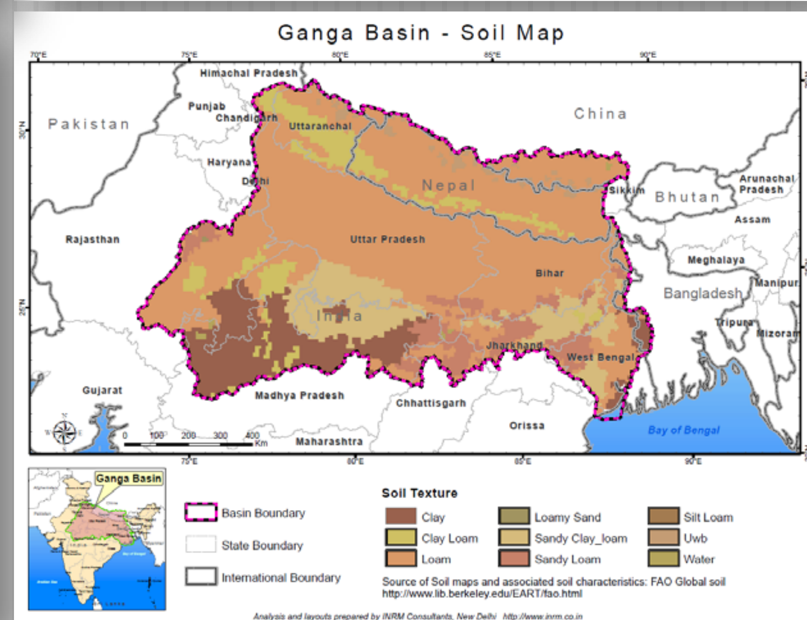
- EU Seventh Framework Programme
- World bank

Basic Data Layers for Modelling









Additional Setup for Snow Modeling

- **Elevation Band**
  - Subbasin – 414
  - No of Elevation Bands – 10 (2000m – 8000m)
  - Subbasin > 4000 m – 13

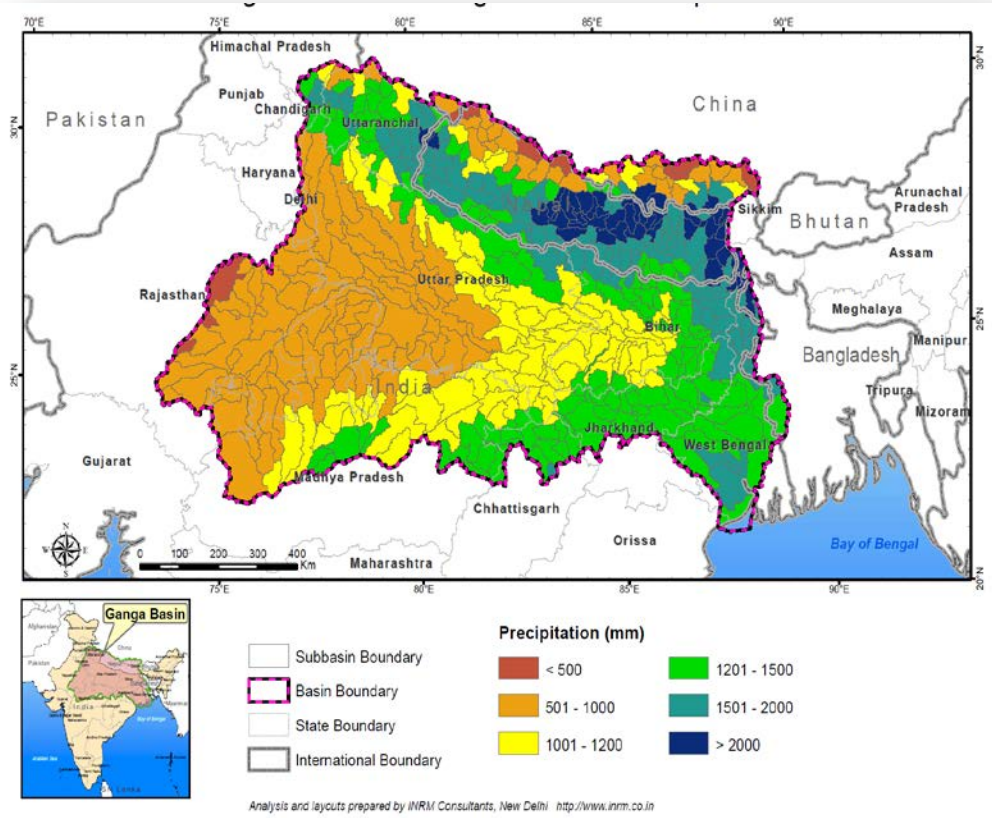
- **Elevation Band Creation**
  - SWAT Topographic report
  - ArcGIS Raster Calculation

Additional Setup for Snow Modeling

- **Lapse Rate** using 10 Elevation Bands (>2000 m)
  - Temperature – (- 6.5°C/Km)
  - Precipitation – (200 mm/Km)

- **Glacier Depth initialization** - 100 m (for altitudes about 4500 m elevation) – after calibration

Spatial Distribution of Average Annual Precipitation and Snow Module Parameterization



- **Snowfall Temperature (SFTMP)**

Val : 2 (-5°C to 5°C) 1

- **Snowmelt base Temperature (SMTMP)**

Val : 2 (-5°C to 5°C) 0.5

- **Melt factor for Snow on June 21 (SMFMX)**

Val : 1.5 (3 to 8 mm H_2O/day-°C) 4.5

- **Melt factor for Snow on December 21** (SMFMN)

Val : 0.5 (3 to 8 mm H_2O/day-°C) 4.5

- **Snow pack Temperature Lag Factor (TIMP)**

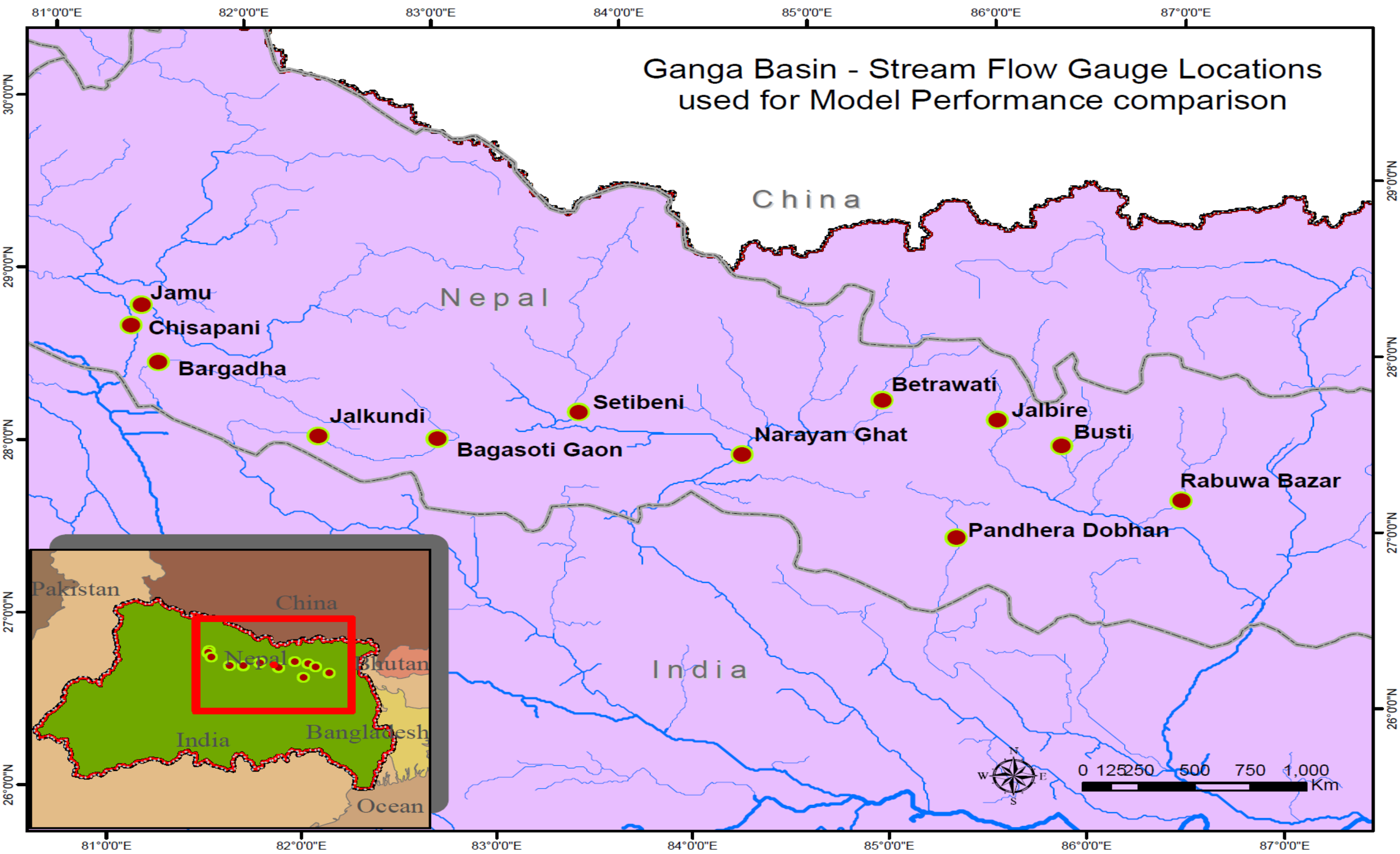
Val : 0.511 (0.01 to 1) 1

- **Minimum snow water content that corresponds to 100% snow cover (SNOCOVMX)**

Val : 1

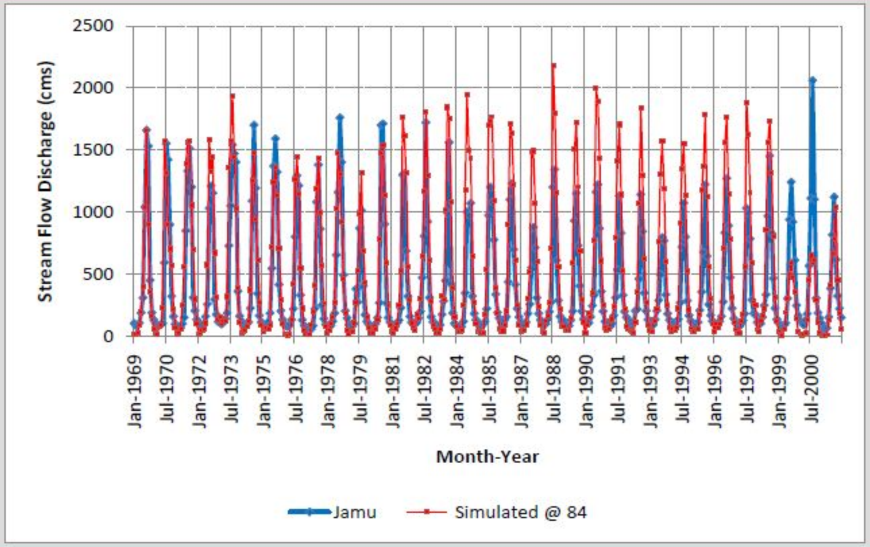
Validation

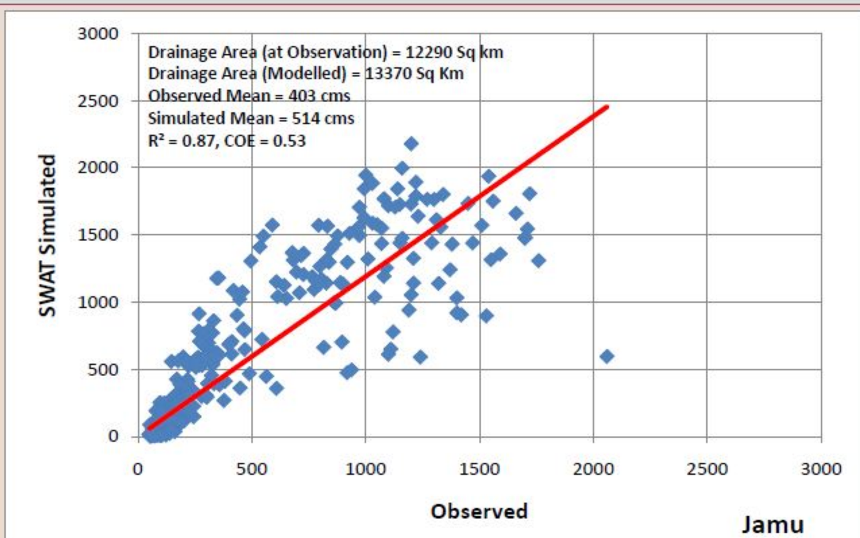
SWAT Output Comparison Locations and Model Efficiency Parameters



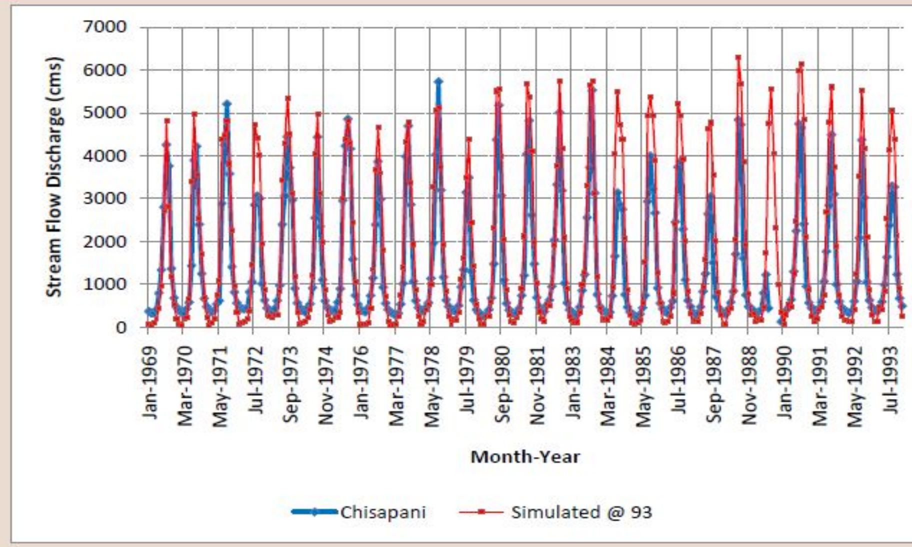
SWAT Output Comparison Locations and Model Efficiency Parameters

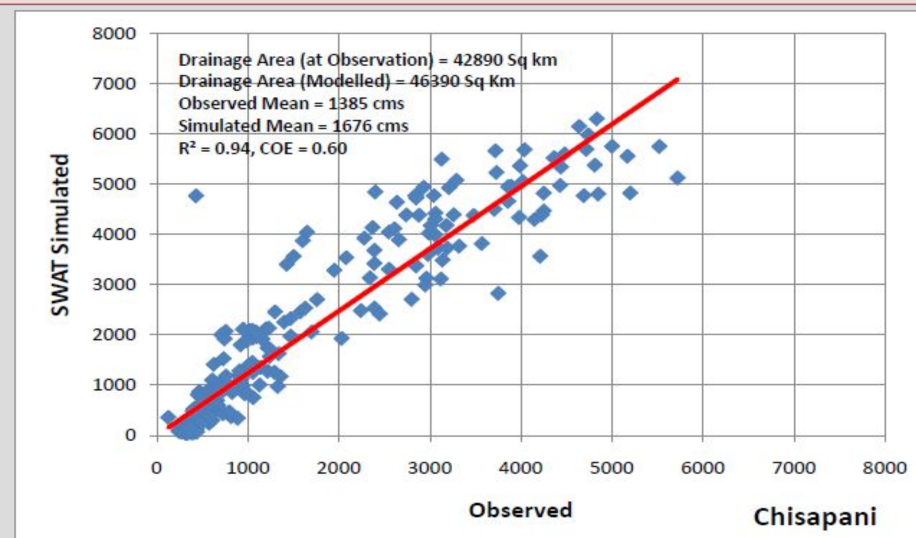
Jamu on Bheri river Catchment area 12,290 sq km. Comparison period: 1969 - 2001





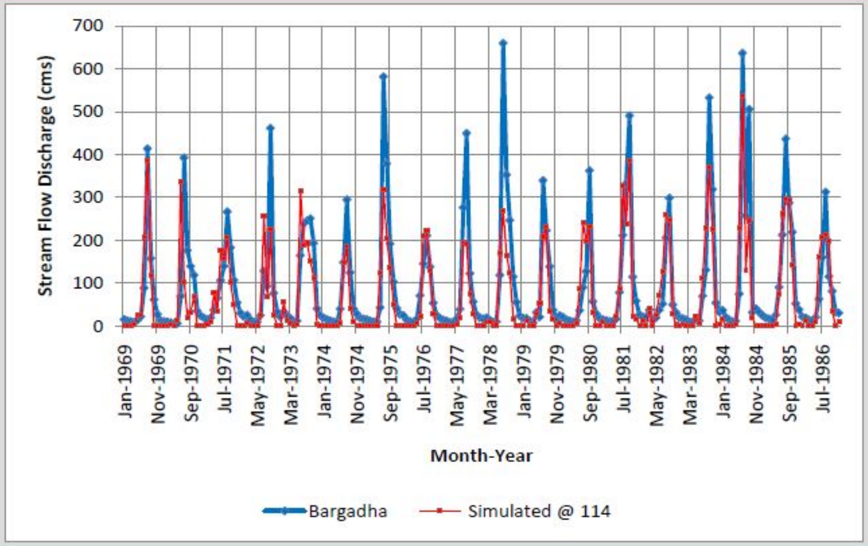
Chisapani on Karnali river Catchment area 42,890 sq km. Comparison period: 1969 - 1993

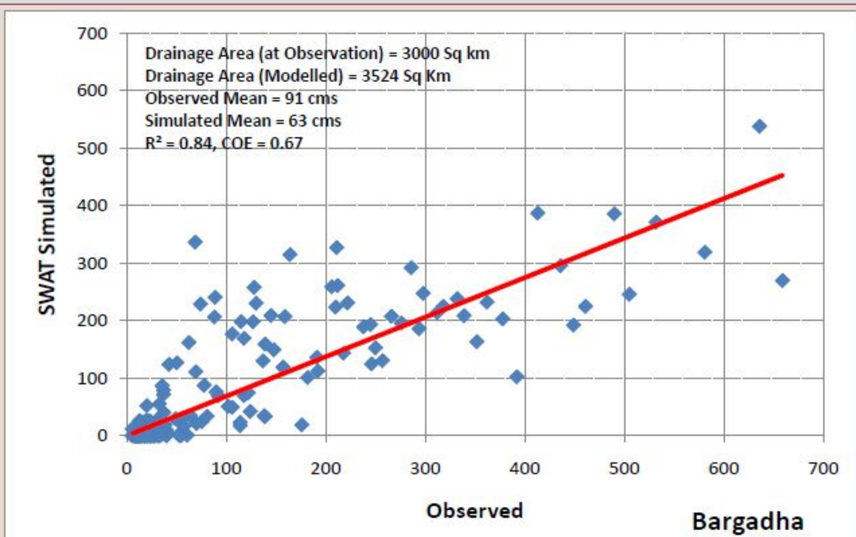




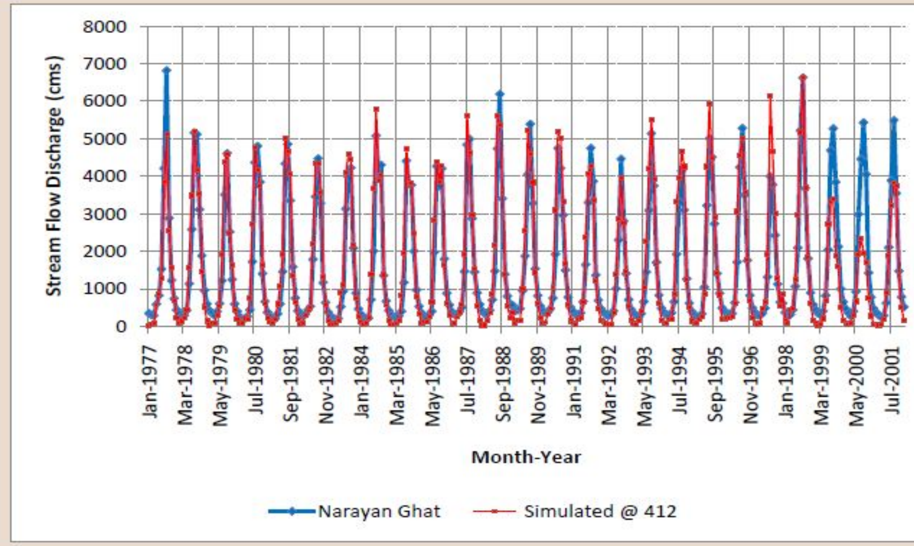
SWAT Output Comparison Locations and Model Efficiency Parameters

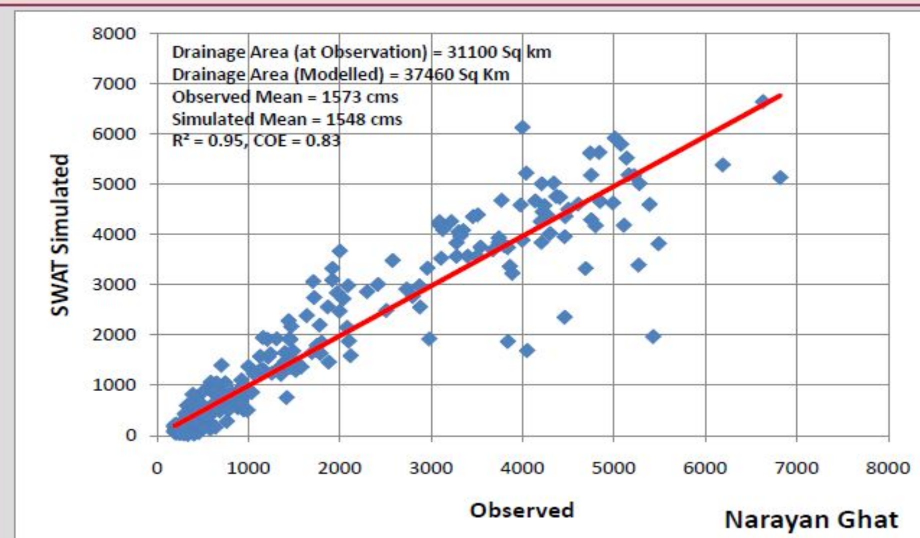
Bargadha on Babai river Catchment area 3,000 sq km. Comparison period: 1969 - 1986



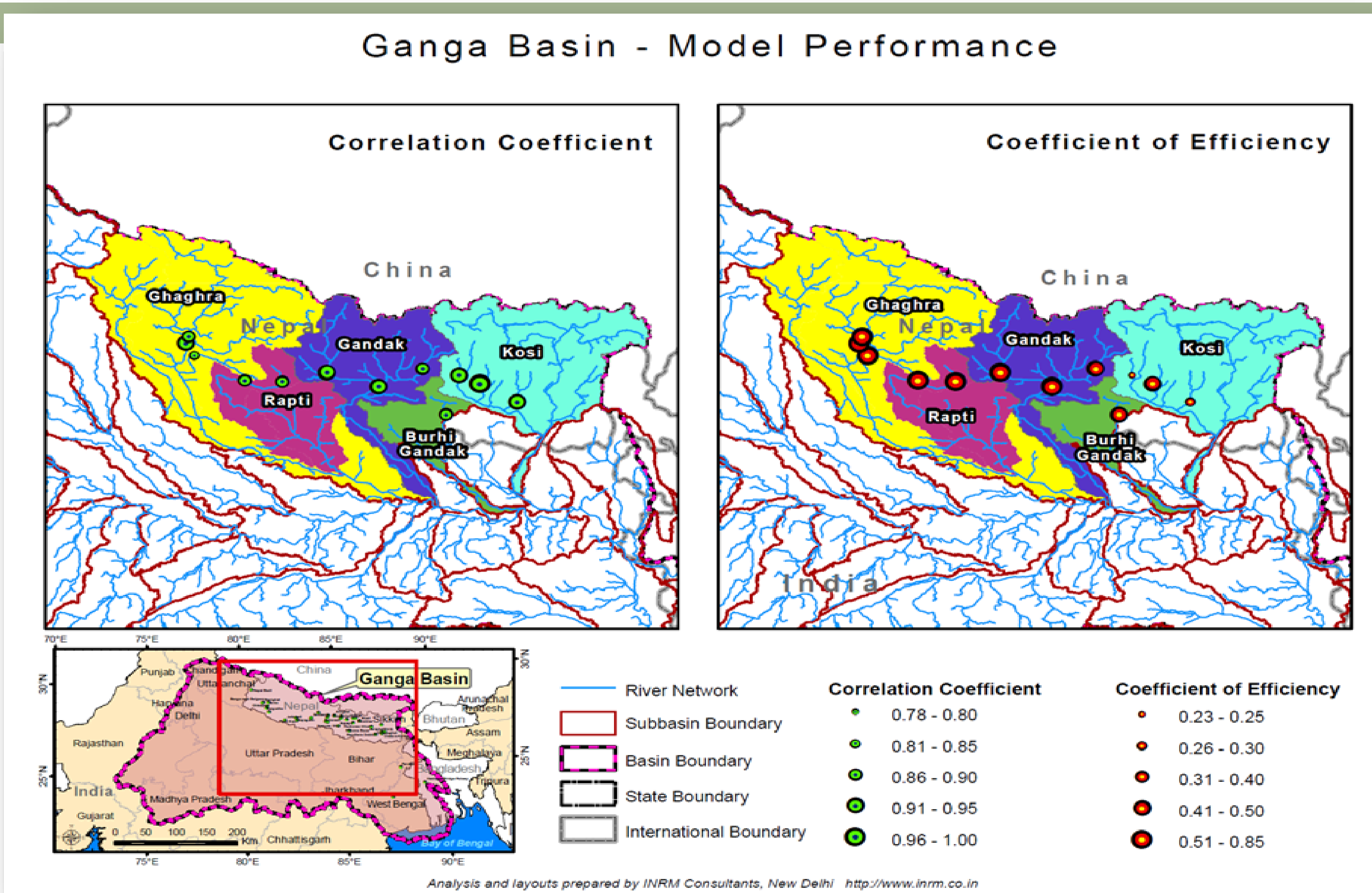


Narayan Ghat on Narayani river Catchment area 31,100 sq km. Comparison period: 1969 - 2001





SWAT Model Performance in the Snow Region

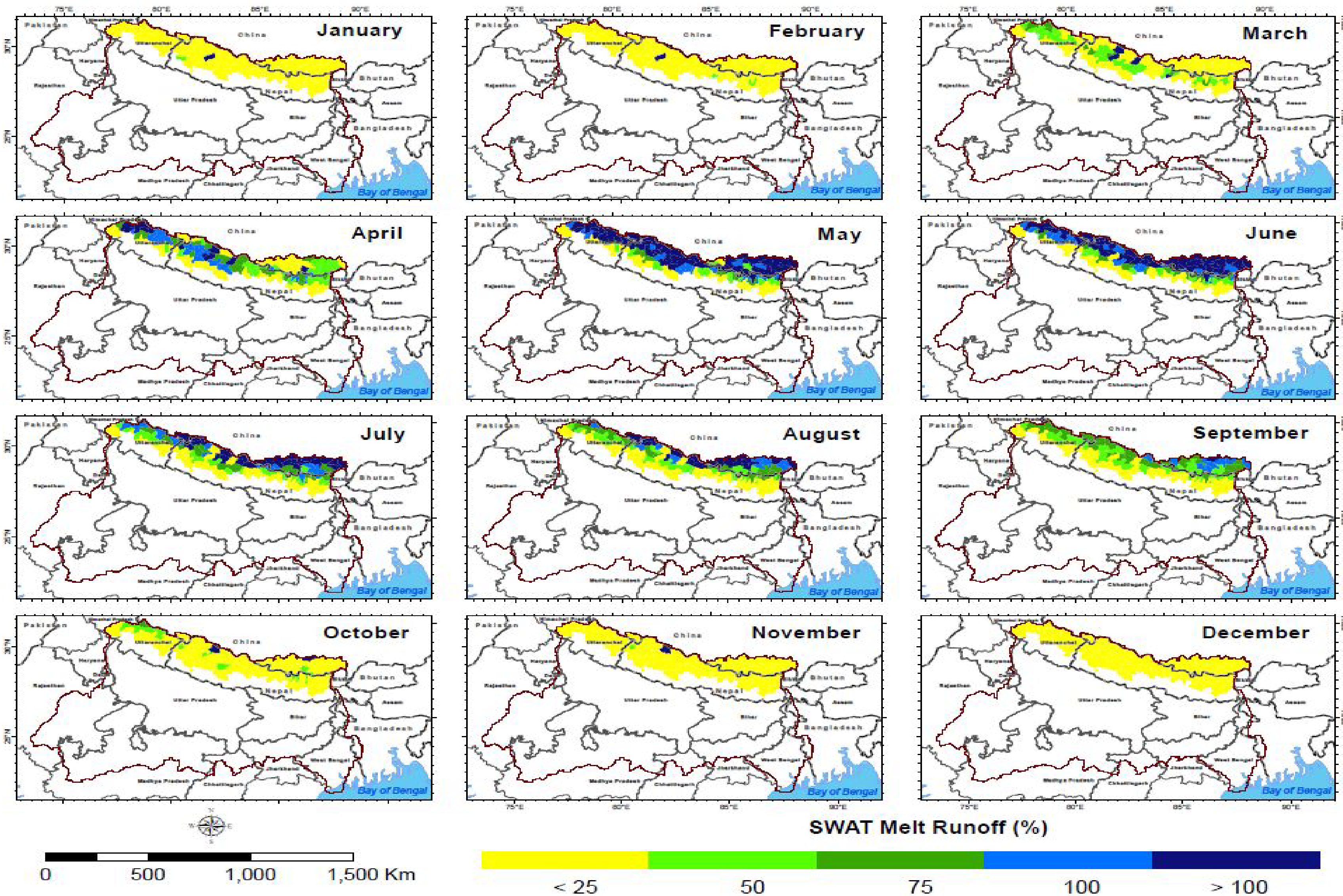


SWAT Output Comparison Locations Model Efficiency Parameters

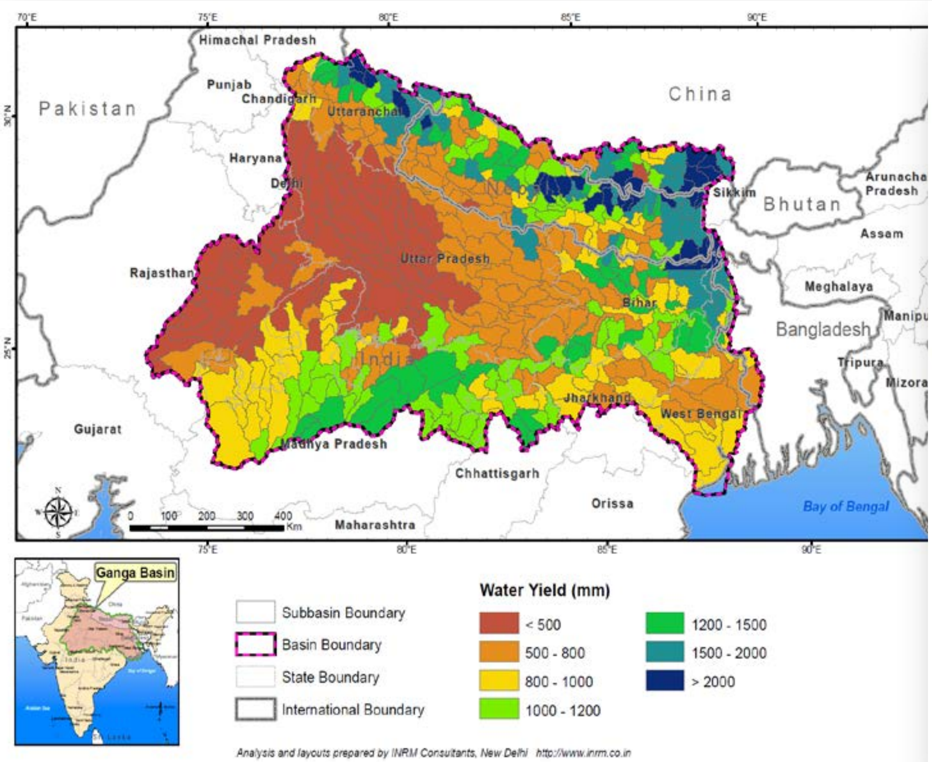
Gauge Site	River	Drainage Area (at Observation) (Sq km)	Start Year	End Year	COE*	Correlation coefficient	Area** Difference (%)	Volume Bias (%)
Ghagra Basin								
Jamu	Bheri	12290	1969	2001	0.533	0.874	-8.79	-27.48
Chisapani	Karnali	42890	1969	1993	0.597	0.942	-8.16	-25.81
Bargadha	Babai (Sarju)	3000	1969	1986	0.67	0.841	-17.47	26.84
Gandak Basin								
Narayan Ghat/ Devghat	Narayani	31100	1969	2001	0.834	0.948	-20.45	-0.70
Setibeni	Kali Gandaki	6630	1969	1993	0.543	0.919	-8.14	10.44
Betrawati	Trishuli	4110	1969	2001	0.444	0.891	-11.56	1.04
Bhuri Gandak Basin								
Pandhera Dobhan	Bagmati	2700	1969	2001	0.494	0.896	-0.37	36.22
Rapti Basin								
Jalkundi	Rapti	5150	1969	1985	0.713	0.870	-1.28	5.17
Bagasoti Gaon	Jhimruk Khola	3380	1976	1985	0.602	0.858	-1.33	10.79

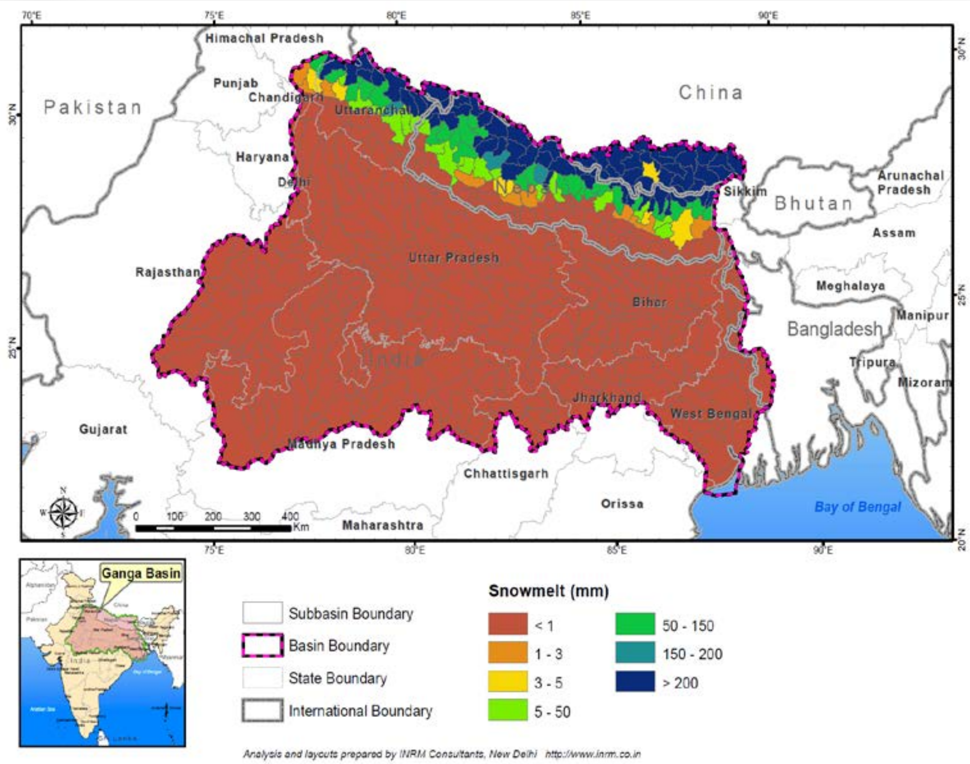
*Nash-Sutcliffe coefficient, ** Difference in Drainage Area (at Observation) and Drainage Area (modelled).

Percentage Contribution of Snowmelt to Stream Flow using Observed Weather Data

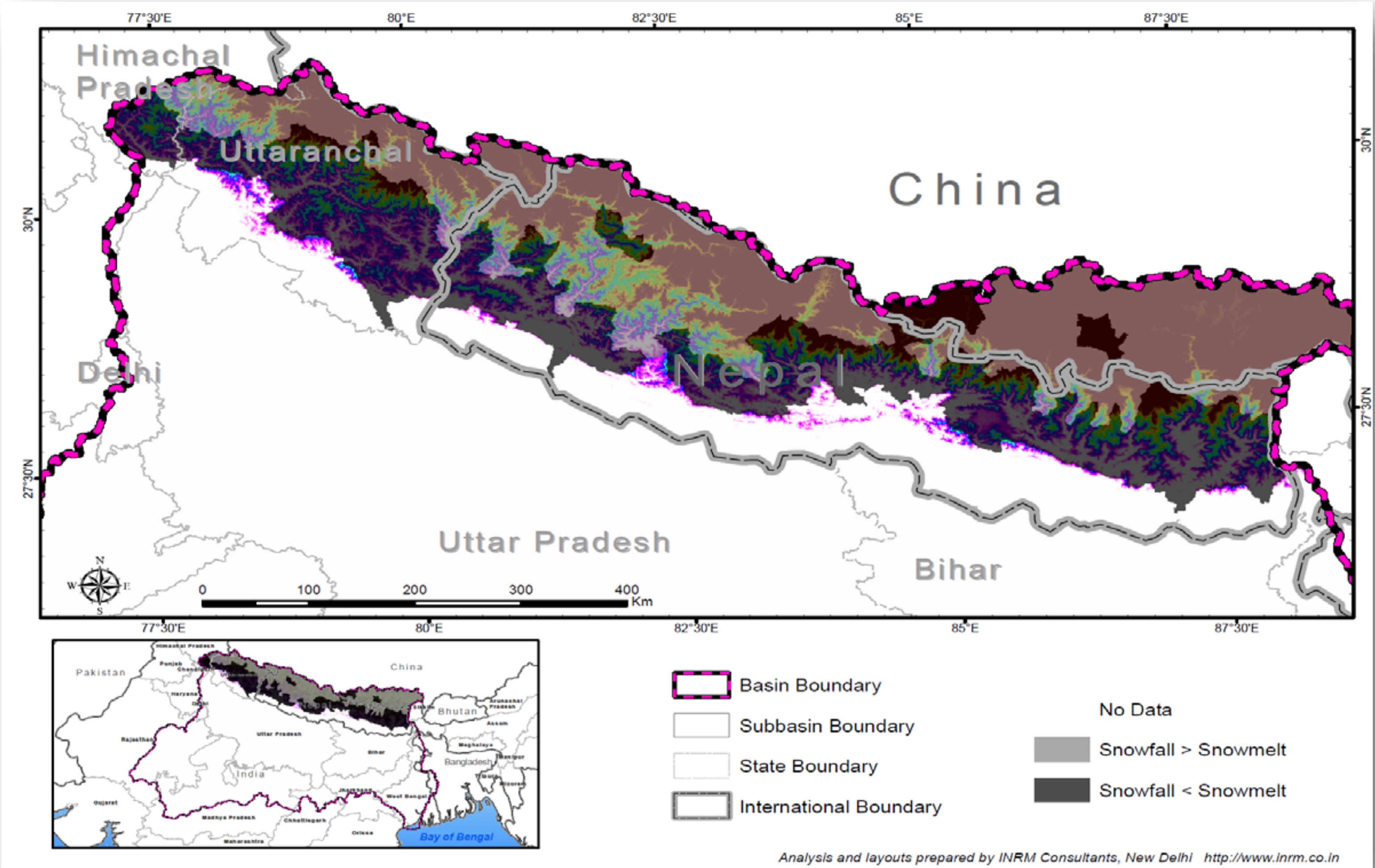


Spatial distribution of Average Annual Water Yield and Snowmelt

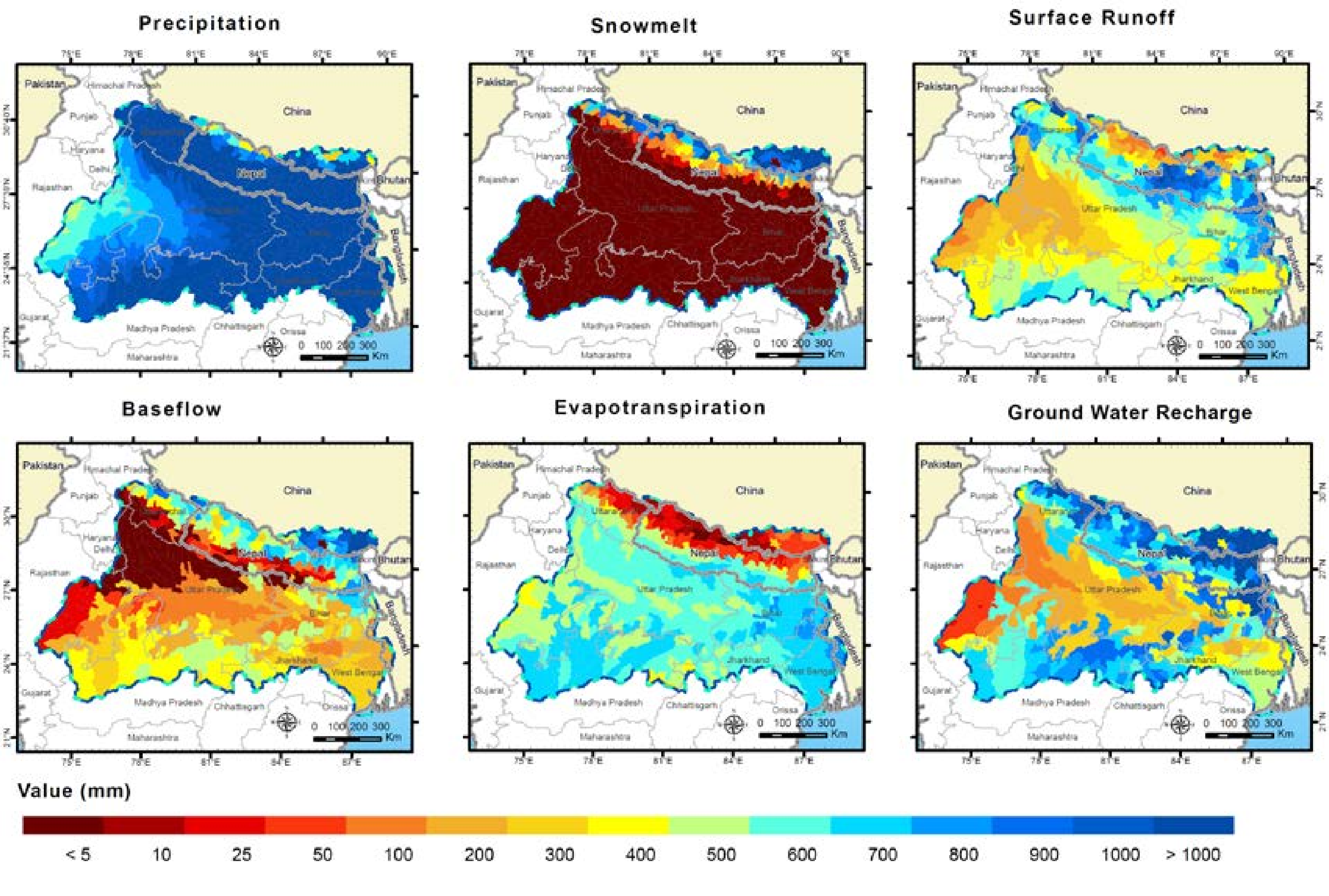




Spatial distribution of Average Annual Snow Hydrology

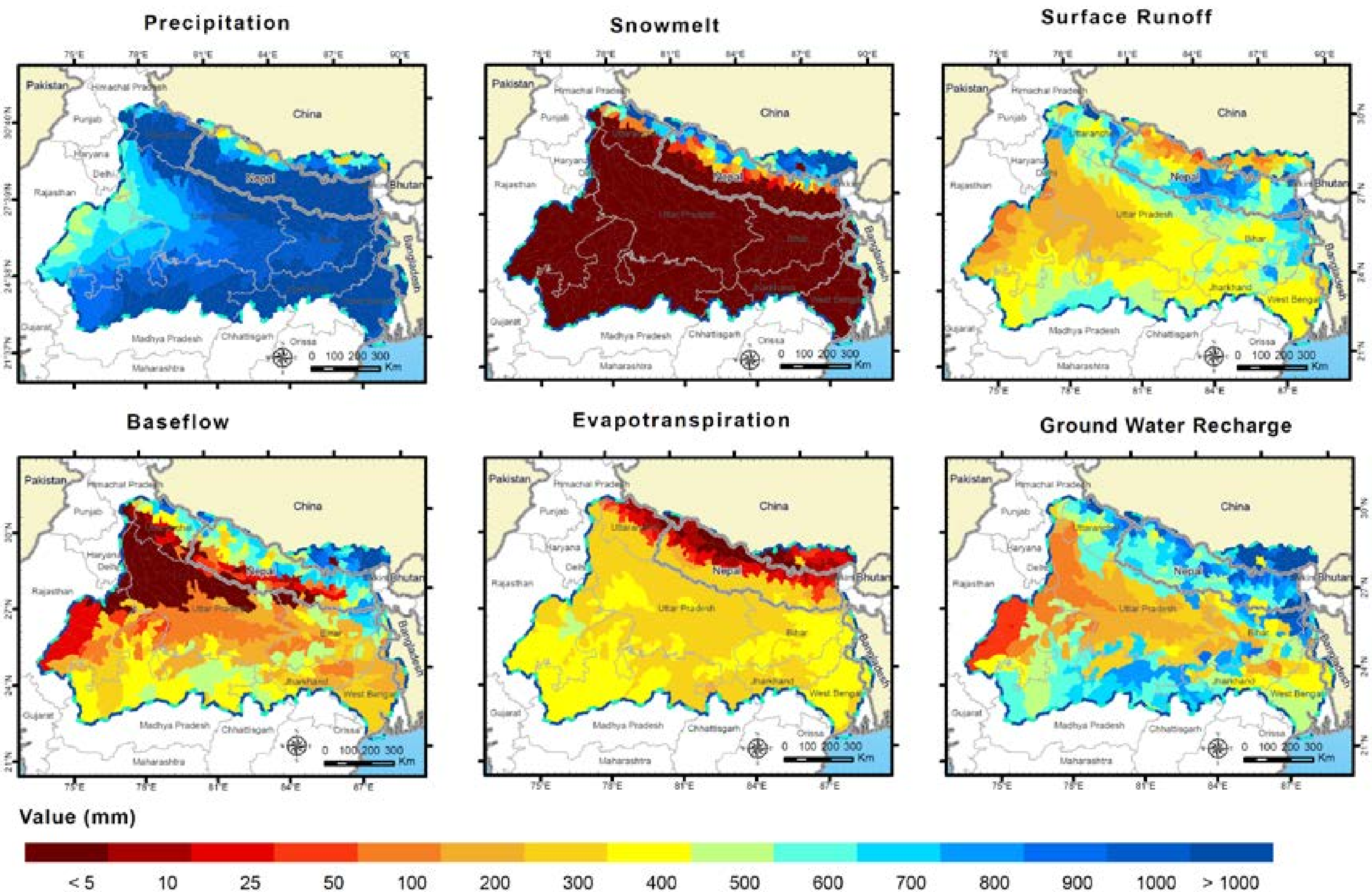


Annual Water Balance Component for Ganga Basin - Simulated using Observed Weather Data



SWAT hydrological model results simulated using observed WATCH weather data (1965 - 2001)

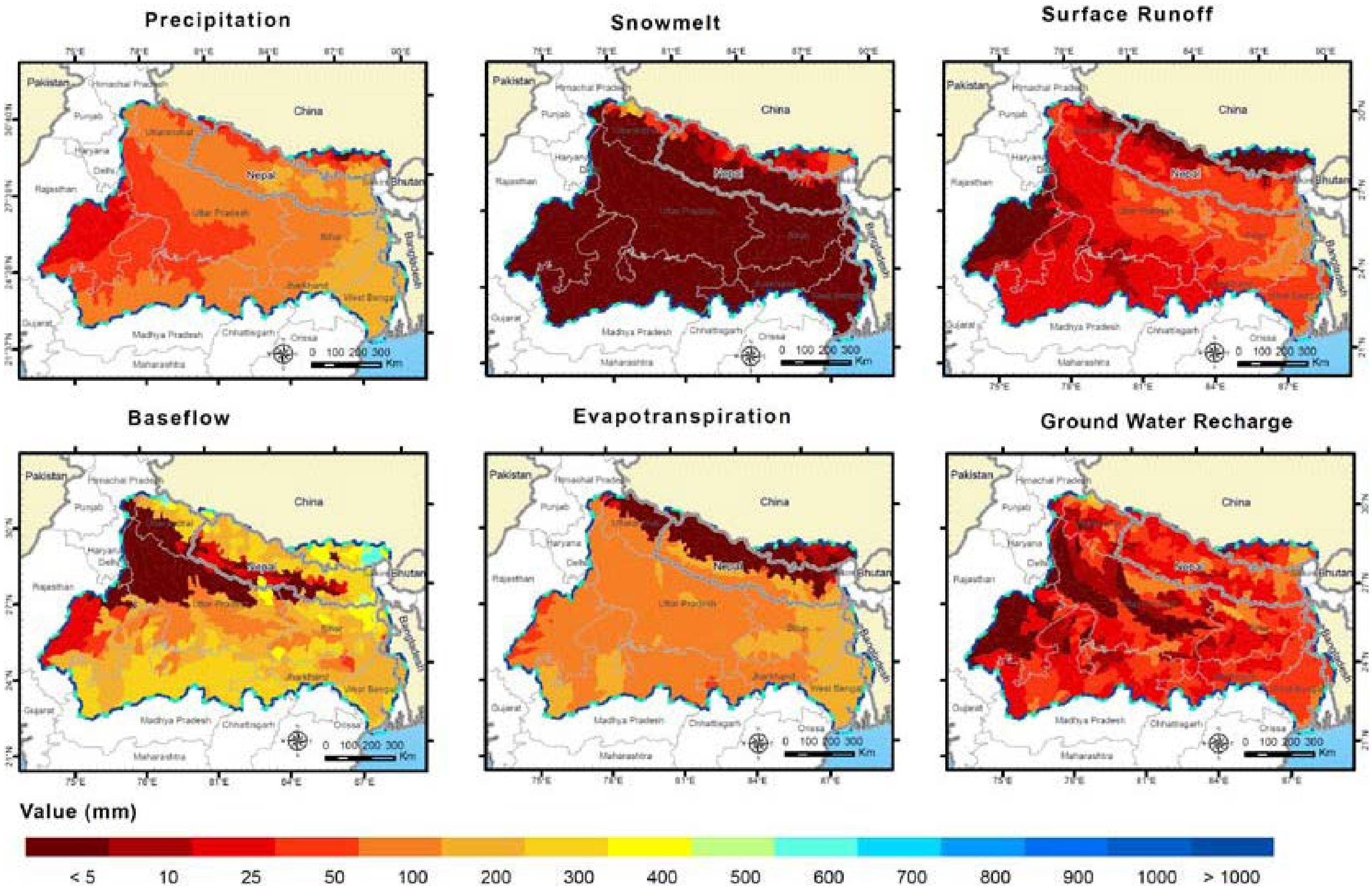
Monsoon (JJAS) Water Balance Component for Ganga Basin - Simulated using Observed Weather Data



* Monsoon (June to September - JJAS)

SWAT hydrological model results simulated using observed WATCH weather data (1965 - 2001)

Post Monsoon (OND) Water Balance Component for Ganga Basin - Simulated using Observed Weather Data

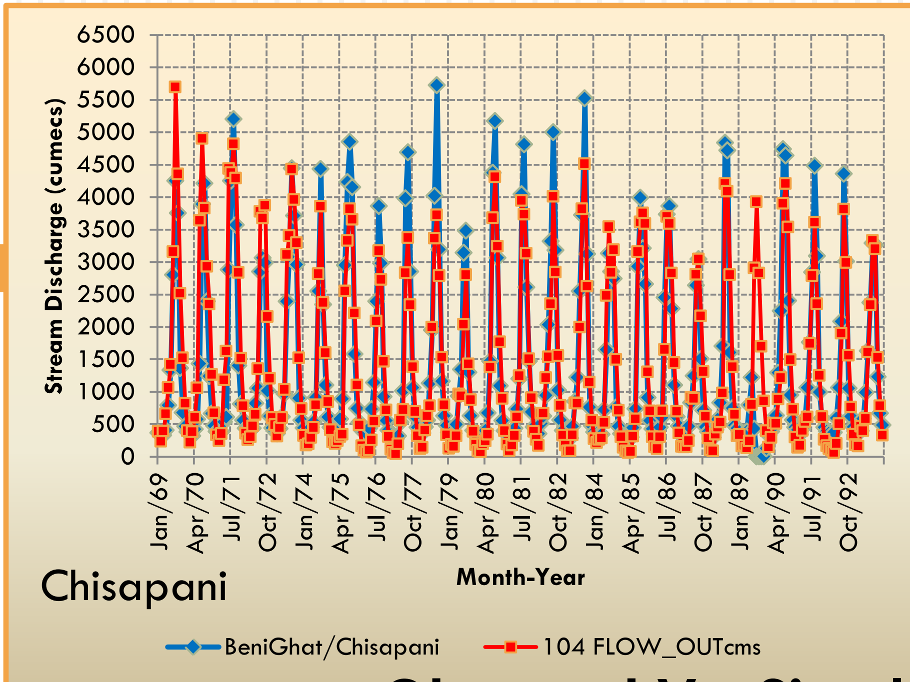


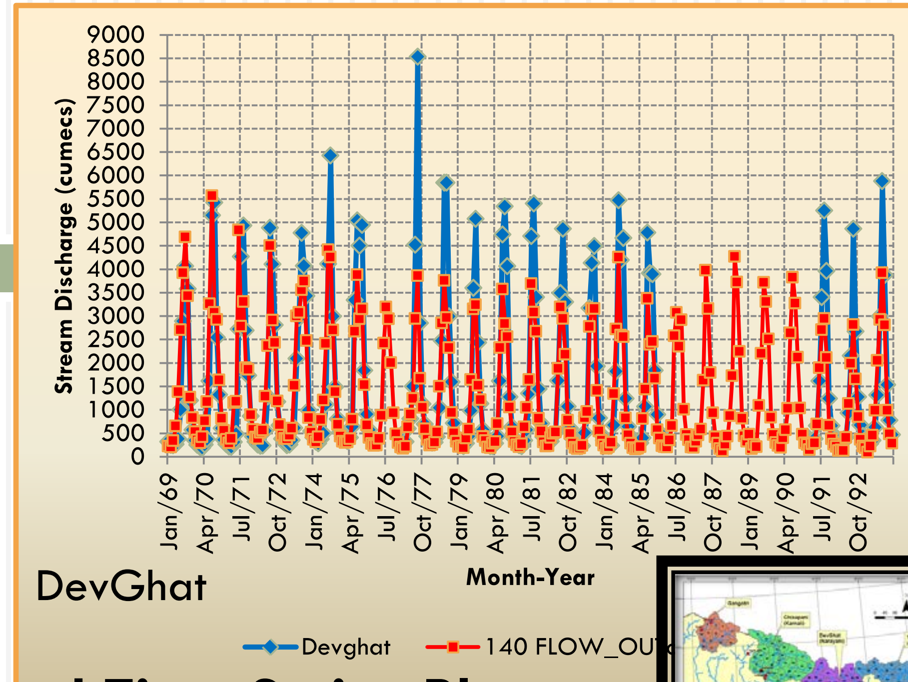
*Post Monsoon (October to December - OND)

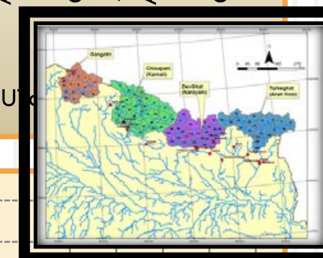
SWAT hydrological model results simulated using observed WATCH weather data (1965 - 2001)

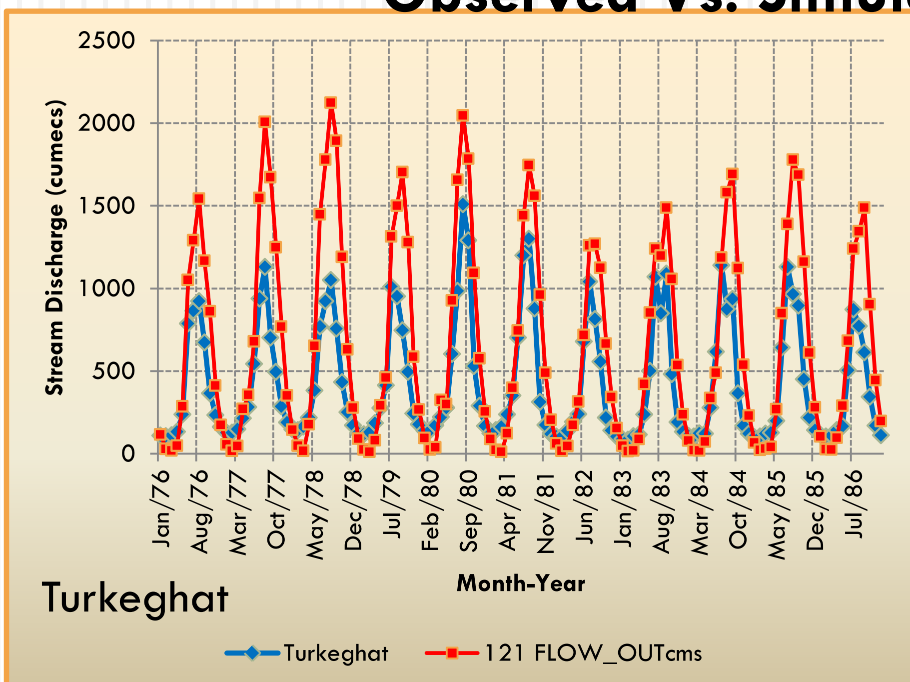
THANKYOU

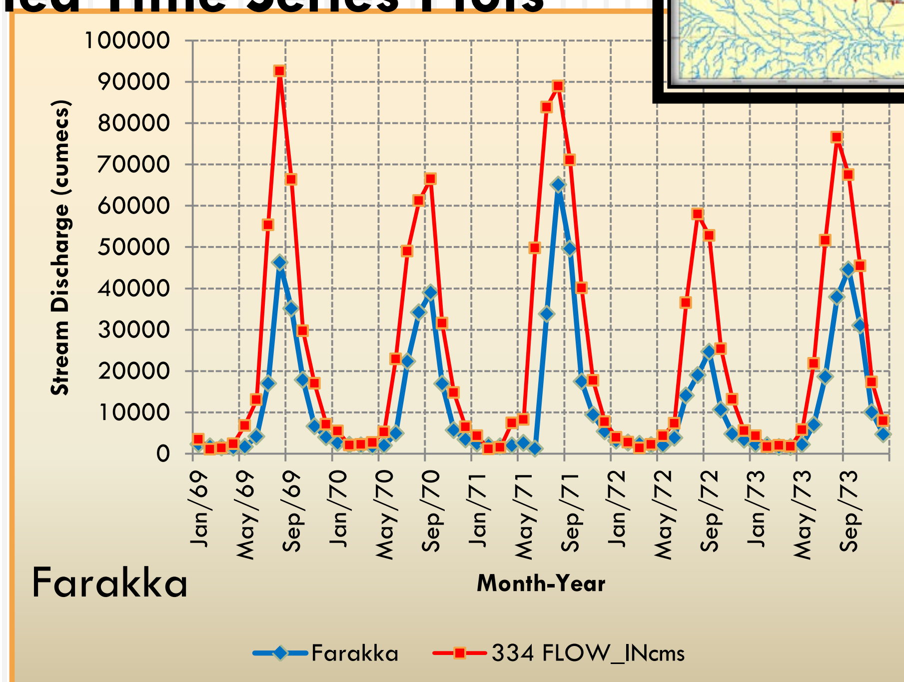
Observed Vs. Simulated Time Series Plots



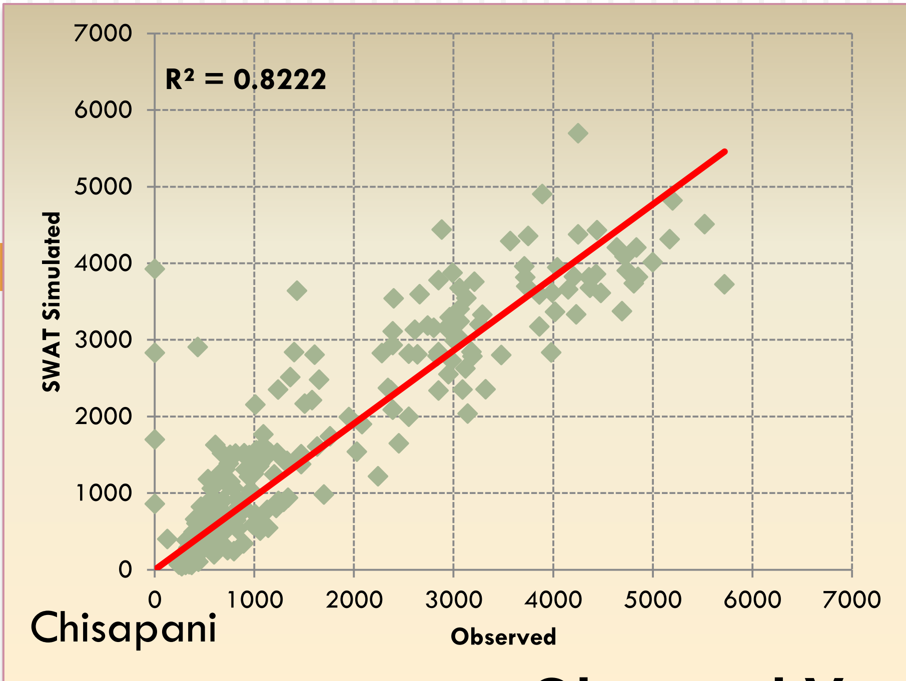


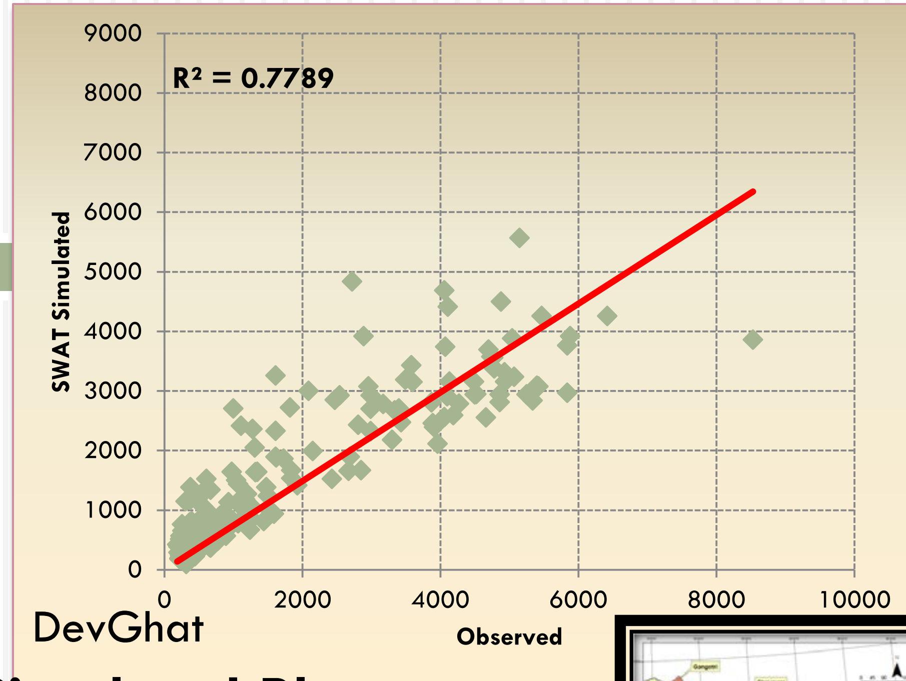


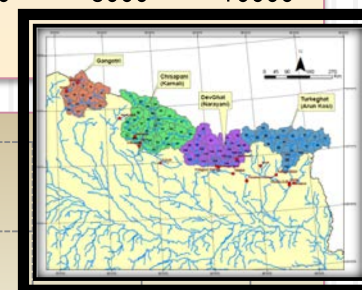


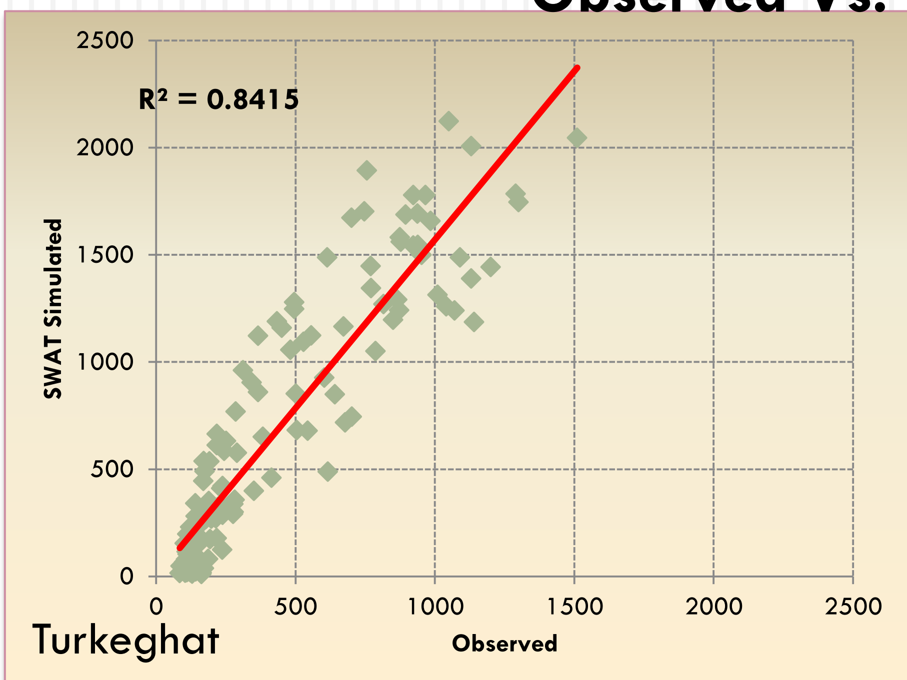


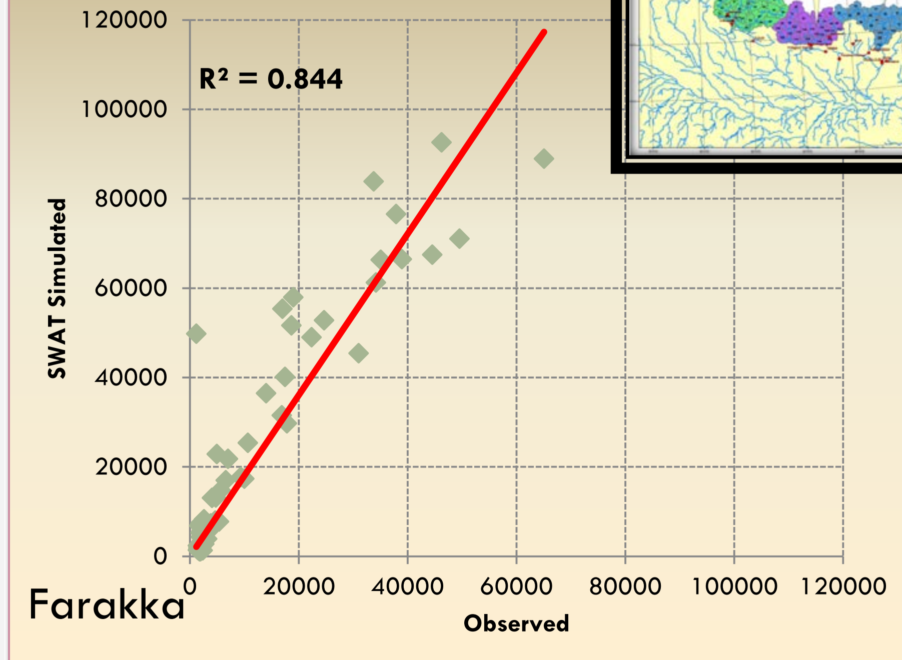
Observed Vs. Simulated Plots











Introduction

The River Ganga has its origin in the western Himalayas surrounded by considerable snow fields / glaciers. From the snouts of these glaciers the principal head stream of the Ganga originates. The contribution of the snowmelt runoff in the Himalayan rivers is significant. The estimation of average contribution of snowmelt runoff is required for water resources development of the region. Soil and Water Assessment Tool (SWAT) model has been used to determine the snow contribution to stream runoff in the Ganga river basin. The model is calibrated for parameters of snowmelt and results are verified at a few Global Runoff Data Centre (GRDC) gauge sites. In the present study, due the absence of any reliable data on snow depths SWAT model simulation have been used to examine the effects of parameterising snow sub-model using temperature and precipitation lapse rate (TLAPS and PLAPS), elevation bands, and snowfall and snowmelt parameters by comparing simulated stream flow with measured stream flow. First level of simulation produced correlation coefficient ranging from 0·7 to 0·85. Simulation of stream flow, improved by using 10 elevation bands, -6.5°C/km TLAPS and 200 mm/km PLAPS with correlation coefficient of 0·95 and Nash - Sutcliffe model efficiency coefficient of 0·83 at Narayanghat gauge site. Sensitivity Analysis was also performed using SWAT-CUP on parameters of snowmelt to identify the most sensitive parameter influencing snowmelt process.

Model Performance

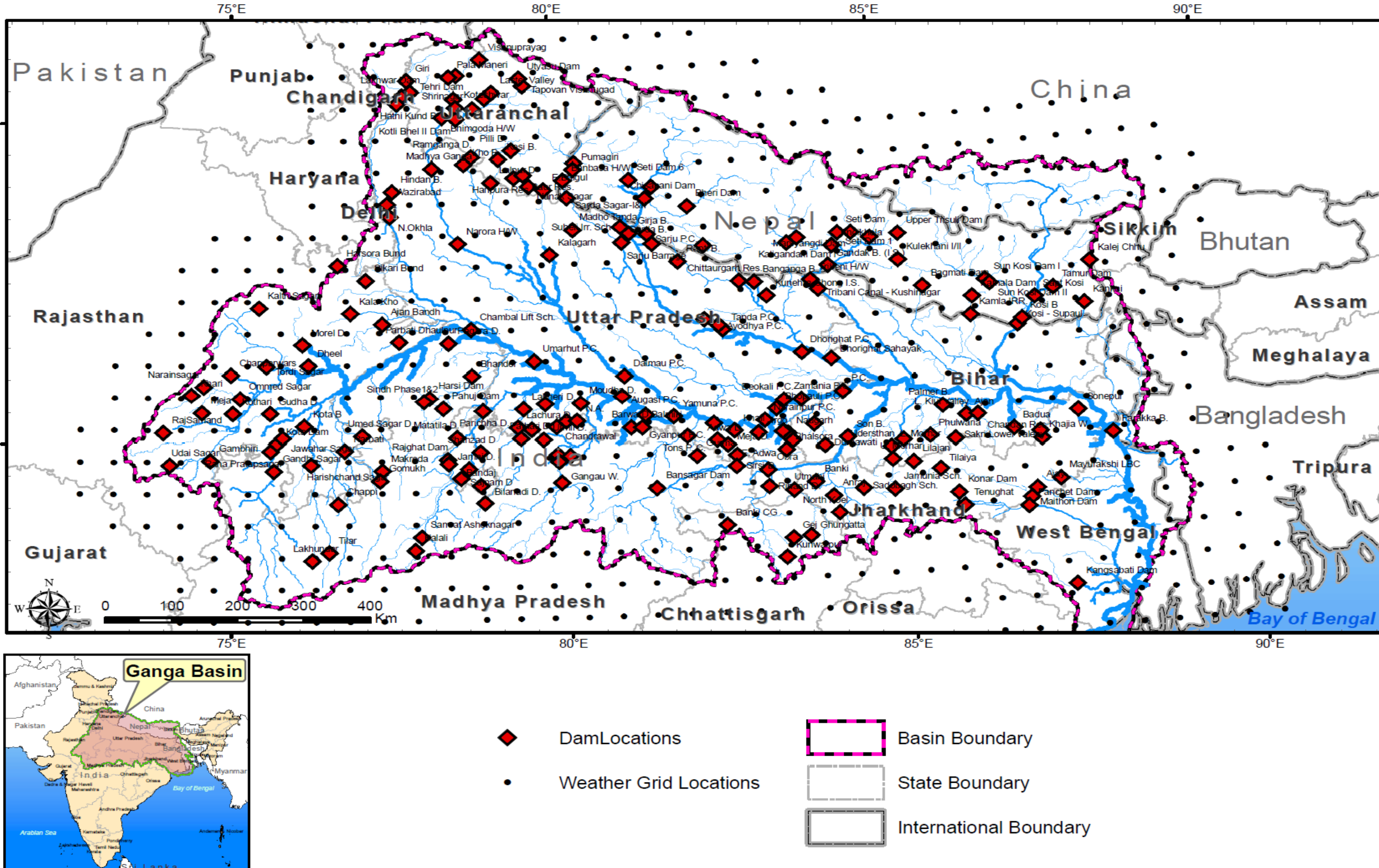
Statistical parameters namely regression coefficients (R2) and Nash Sutcliffe coefficient (NS) were used to assess the model efficiency on monthly SWAT hydrologic streamflow predictions.

Model Evaluation Statistics (Dimensionless)

Nash-Sutcliffe efficiency (NSE): The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

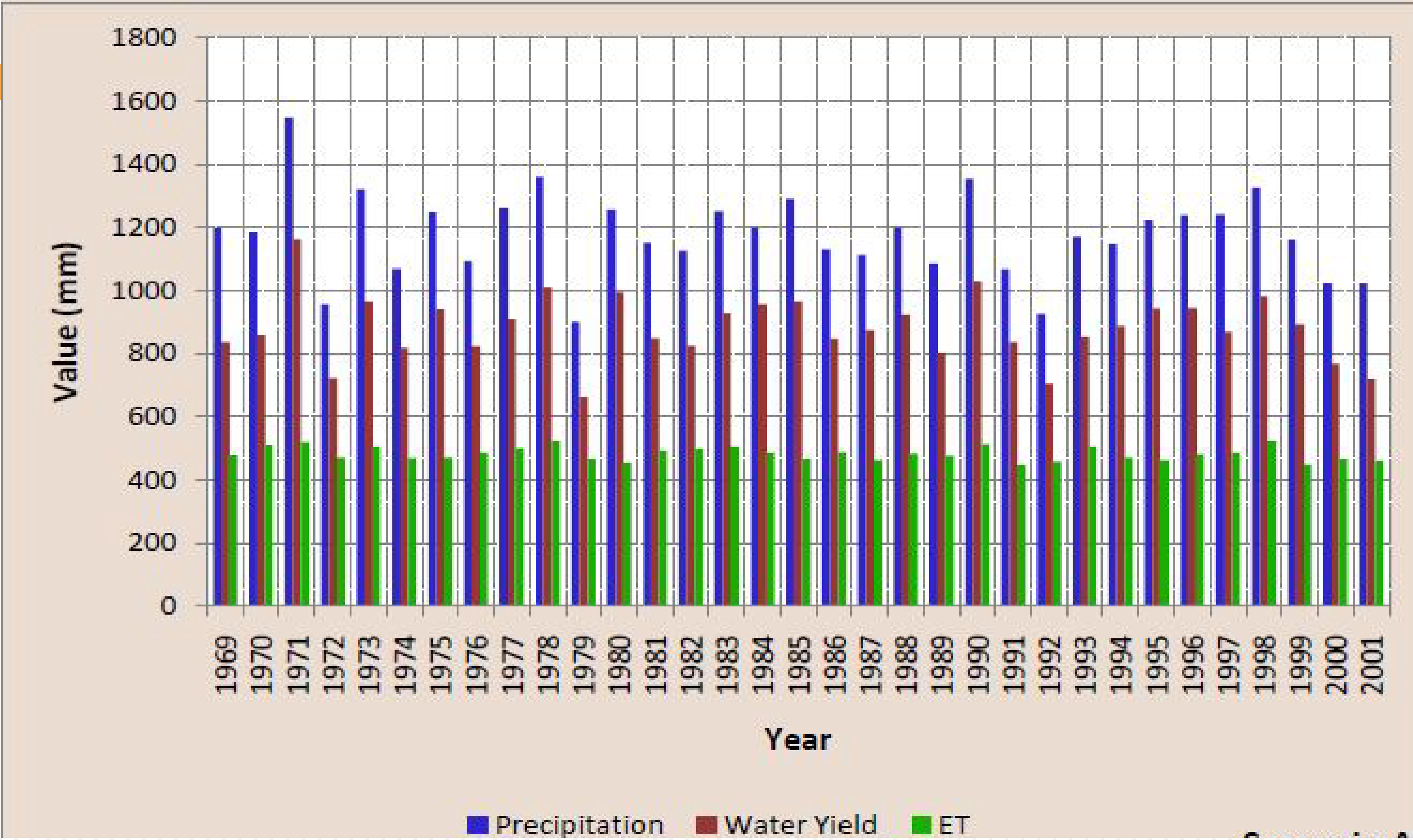
Coefficient of determination (R^2): *Coefficient of determination (R^2) describes the degree of collinearity between simulated and measured data. R^2 describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered* acceptable (Santhi et al., 2001, Van Liew et al., 2003). R^2 is oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999

Hydro-Meteorological and Water Resources Structures Data

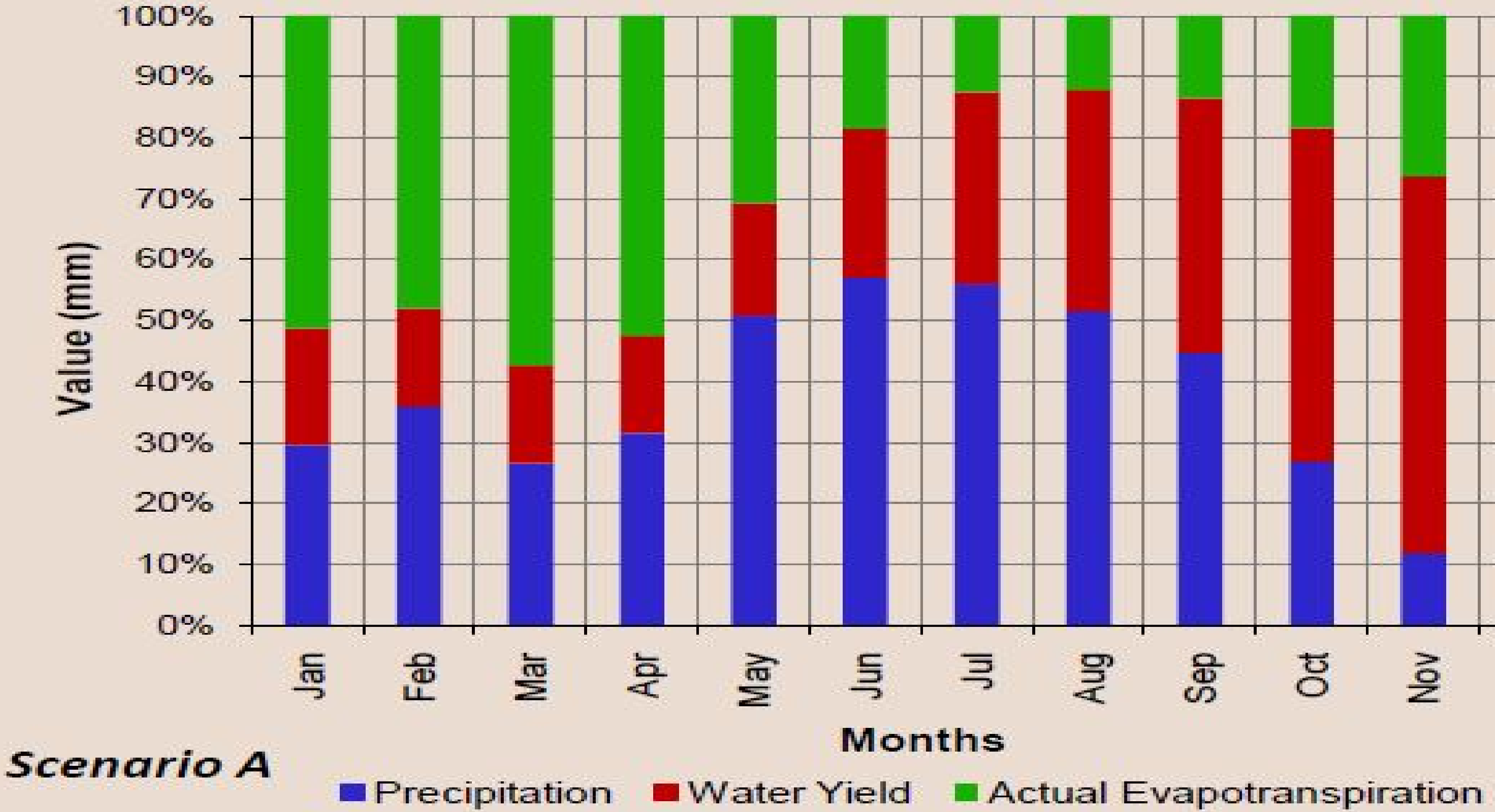


Analysis and layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

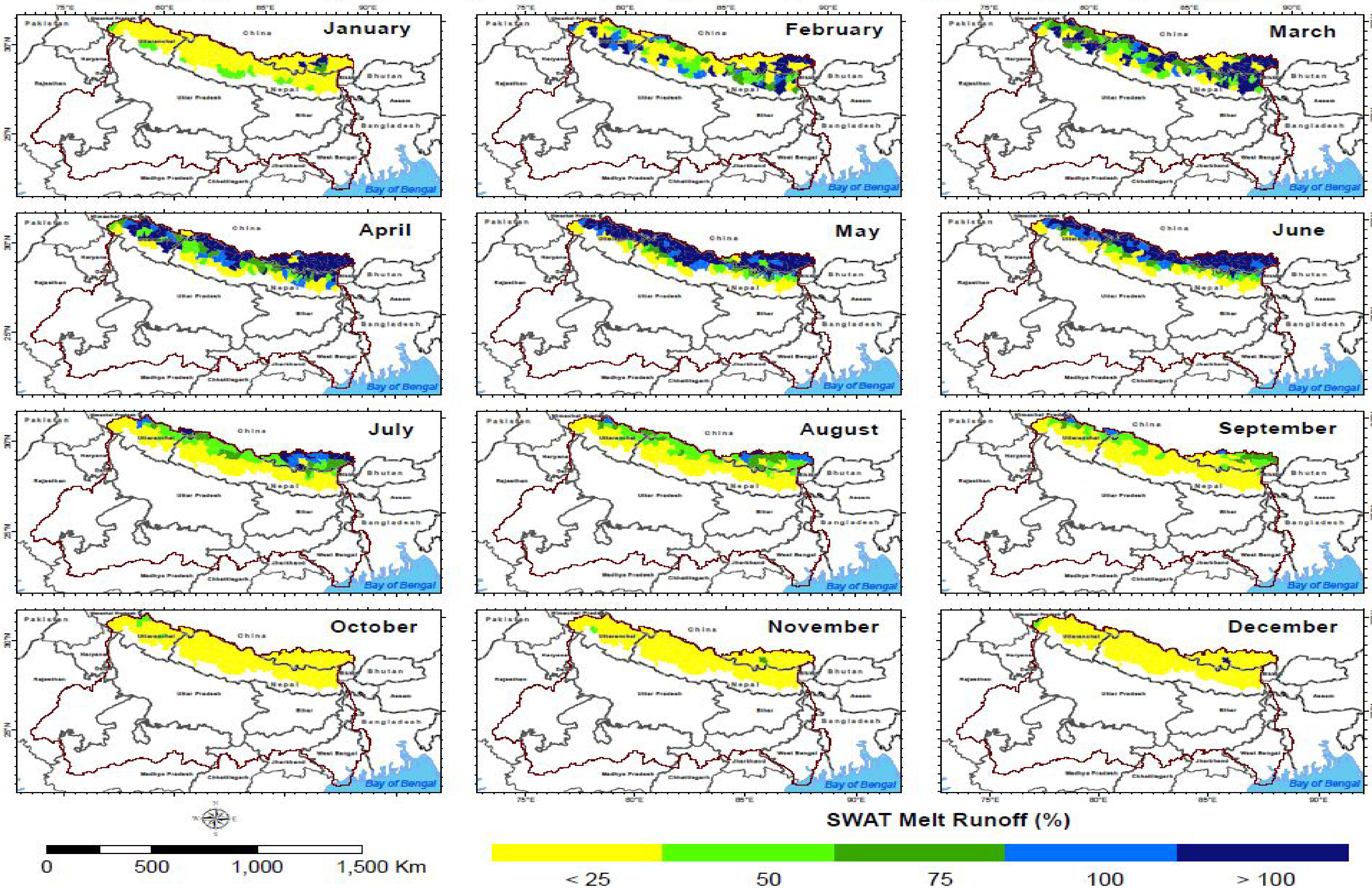
Annual Water Balance – Ganga Basin



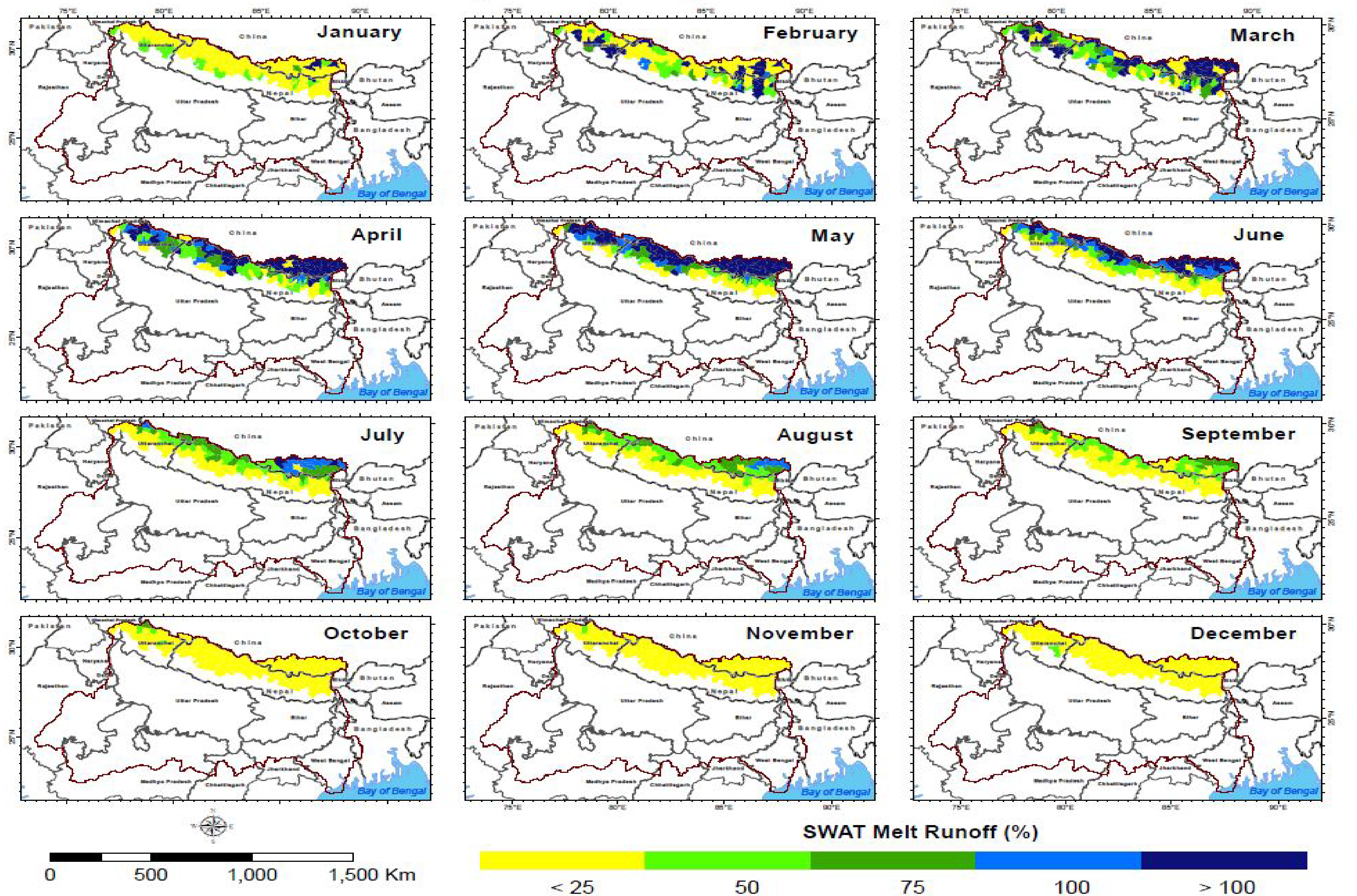
Average Monthly Water Balance – Ganga Basin



Percentage Contribution of Snowmelt to Stream Flow using Observed Baseline Data



Percentage Contribution of Snowmelt to Stream Flow using Observed Mid Century Data



Percentage Change in Annual Average Snowmelt – Change from Baseline to Mid Century

(IPCC SRES A1B Scenario)