Estimation of discharge from Langtang River Basin, Rasuwa, Nepal using glacio-hydrological model

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Introduction

- **The prediction of runoff from Himalayan headwaters is a crucial element for sustainable development of the Himalayan countries**
- **Estimation of discharge is highly related to melting of snow and ice in the Himalaya.**
- **Several models and empirical relations have been proposed to calculate glacier ablation and discharge in the Himalaya.**
- **Positive Degree Day (PDD) Model (requires less amount of data)**

Objectives

- **To estimate discharge of Langtang River basin from 2010 - 2050 using PDD Model**
- **To know the contribution of snow and ice melt in the total discharge**
- **To analyze the sensitivity of PDD Model**

Study Area

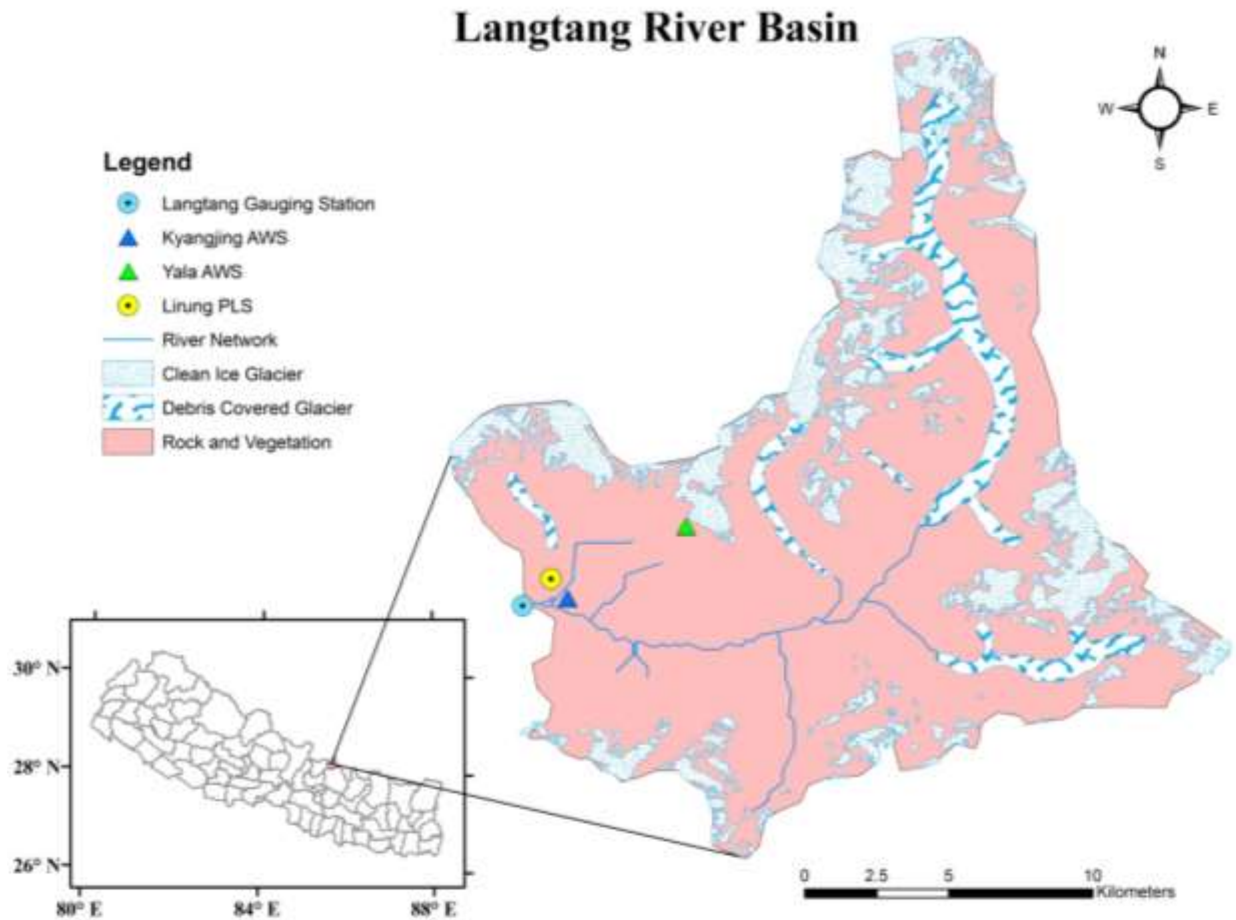
•Elevation : 3600 – 7234 m a.s.l

•Total area: 359.25 km²

•Snow and Ice: 74.18 km² (20.65%)

•Debris: 26.95 km² (7.5%)

•Rock and vegetation: 258.12 km²



Methods and materials used

- **Positive Degree Day Model is used to estimate the discharge**
- **Using monthly temp and precipitation (from DHM)**
- **Information regarding glacier area was extracted from Landsat image**

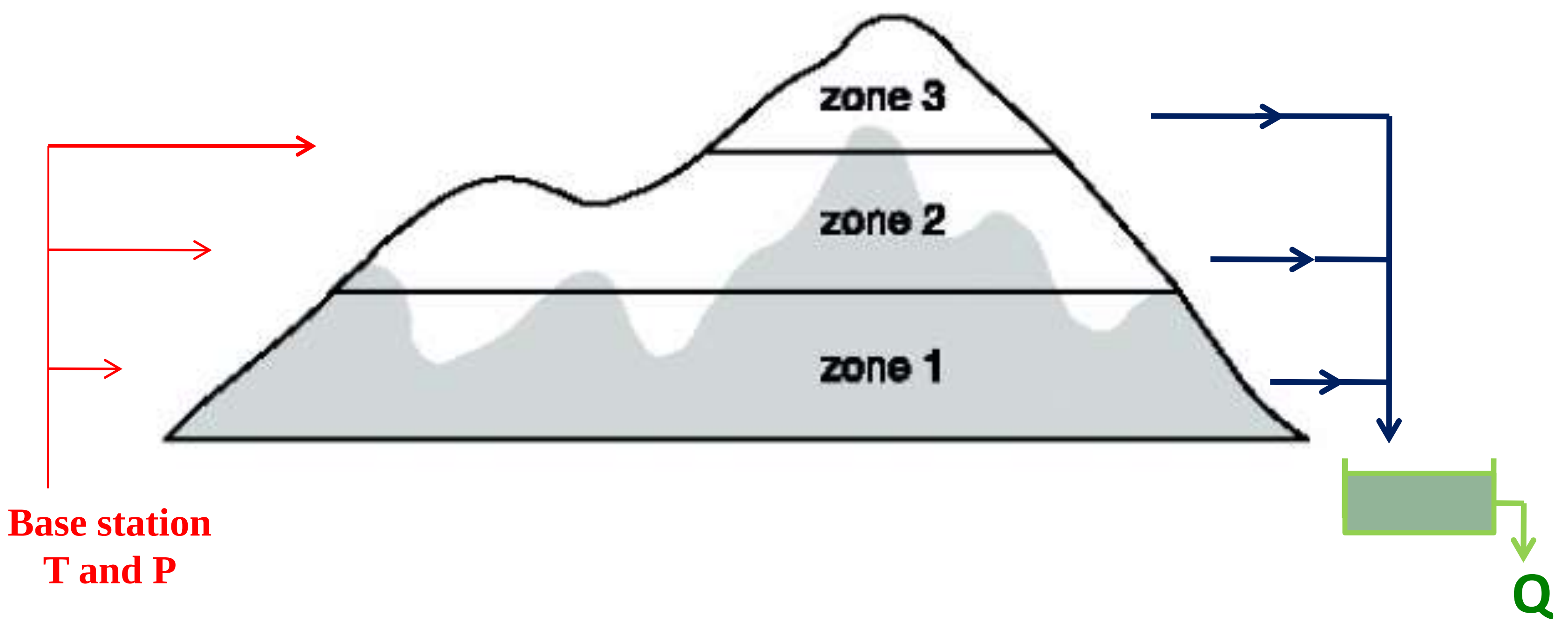
Basin was divided in to 18 elevation zones

Precp. & Temp extrapolated from Kyangjing base house and snow and ice melt in each zone computed

Snow, ice, debris, rock and vegetation area are calculated to determine melting area information

Total discharge (Q) = ∑discharge from each zone

Basic concept of PDD model



Temperature and precipitation gradient

- **Precipitation gradient:**

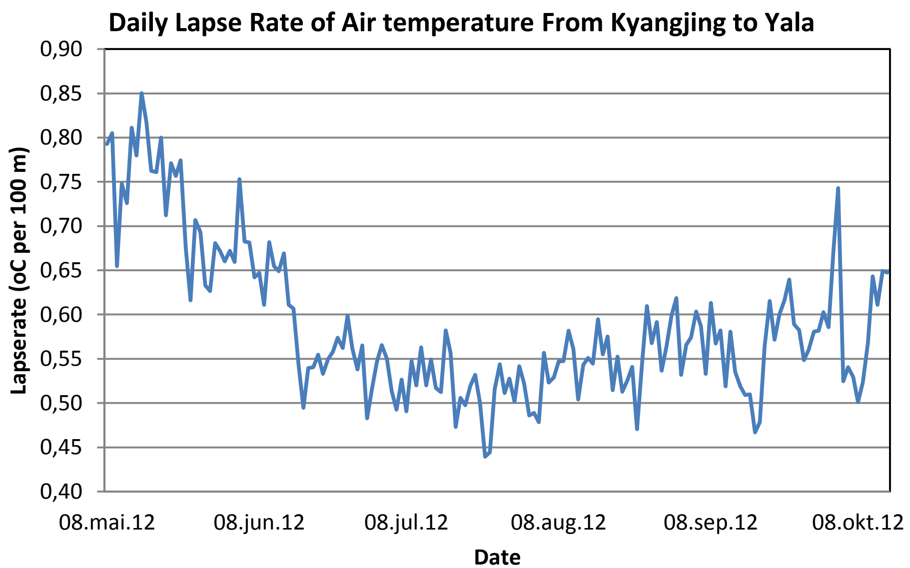
$P_z = P_{BH}\{1+0.0003(z-4000)\}$ $4000 \leq z \leq 5000$ m (Seko et al., 1987)

$P_z = 1.39\ P_{BH}$ z >5000 m (observed data from 8 May – 2 Dec 2012)

- **Average temperature lapse rate:**

0.59 °C per 100 m

(observed data from 8 May – 2 Dec 2012)



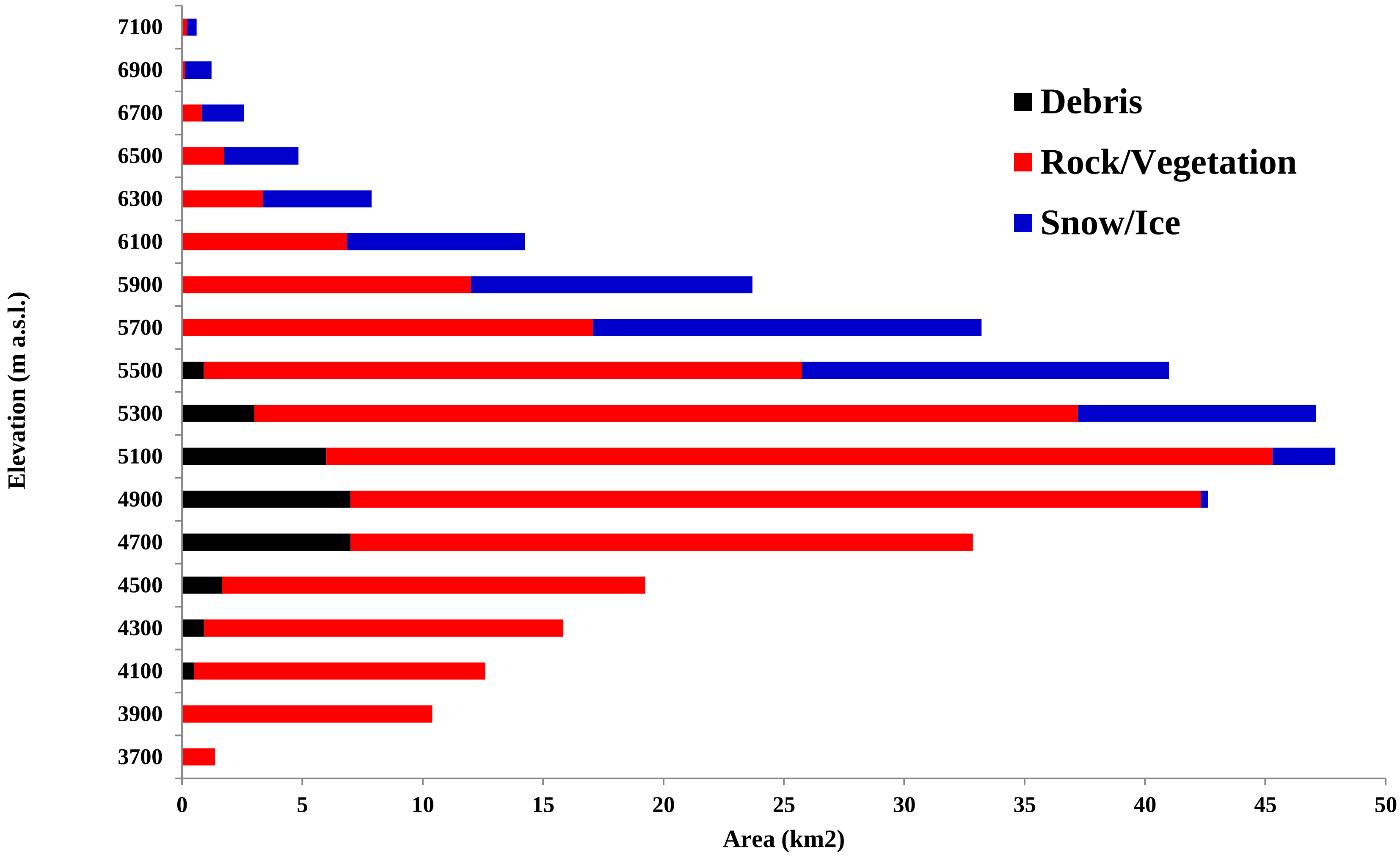
Projected temperature and precipitation (2010 – 2050)

- WRF RCM data for the RCP 4.5 scenario is used. (12 km x 12 km horizontal resolution)

- The WRF output from 1996 to 2009 is used for model comparison and bias correction.

- The RCM output is bias corrected by using the equation given by Cheng et. al, 2007 and Terink et. al, 2010 for temperature and Nazrul et. al, 2009 for precipitation.

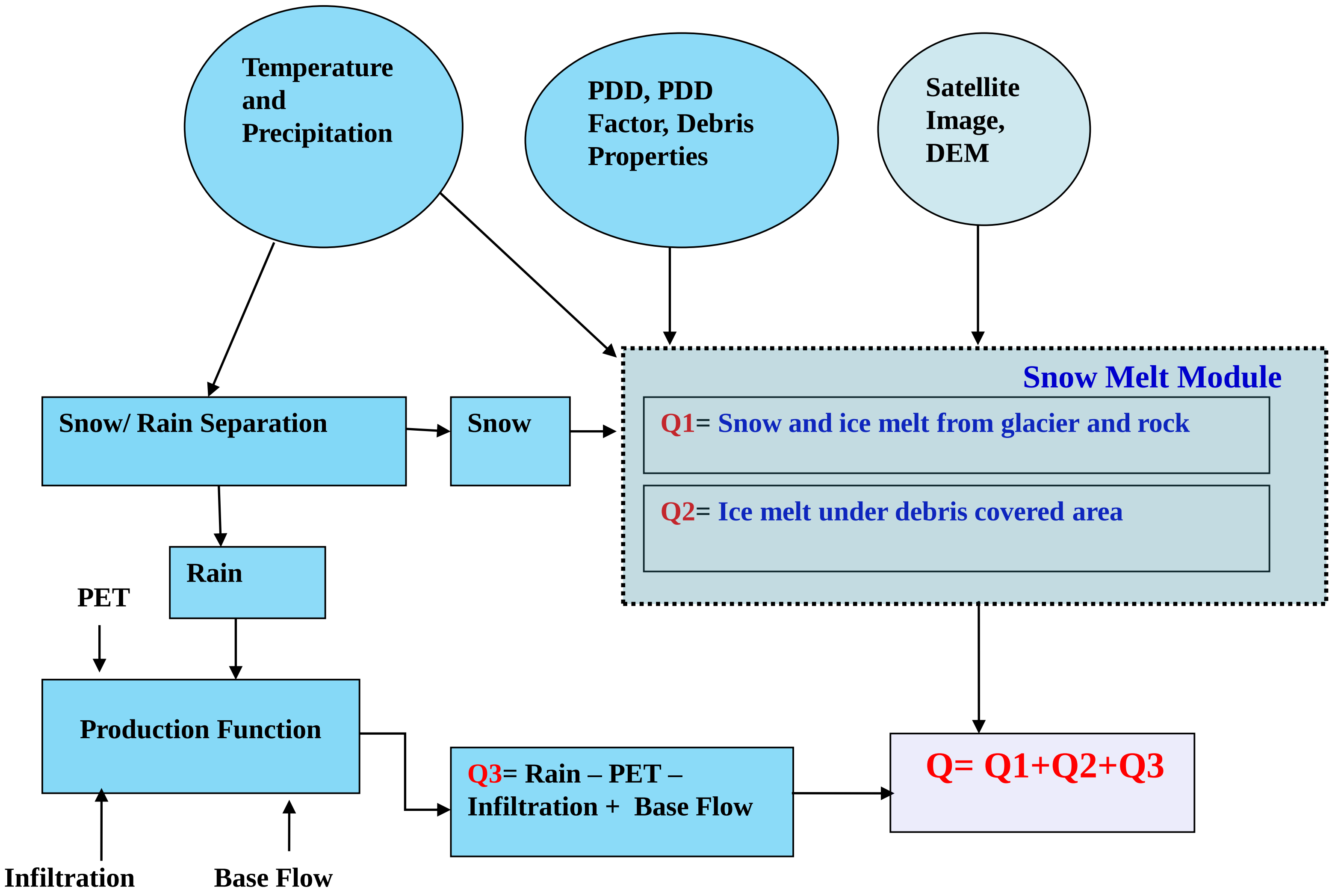
Hypsography and Land Cover Pattern



Input Parameters and factors

k_s	Degree day factor for snow ablation	4.0 – 10.0 mm d^{-1} $^oC^{-1}$ (up to 5000 m) 7.5 – 13.5 mm d^{-1} $^oC^{-1}$ (above 5000 m) (Kayastha et al., 2000a; Kayastha et al., 2003)
k_b	Degree day factor for ice ablation	5.0 – 11.0 mm d^{-1} $^oC^{-1}$ (up to 5000 m) 6.5 – 12.5 mm d^{-1} $^oC^{-1}$ (above 5000 m) (Kayastha et al., 2000a; Kayastha et al., 2003)
k_d/k_b	Ratio of degree day factor for debris covered ice to degree day factor for bare ice	0.5 – 0.58 *(*Kayastha et al. 2000b)
low_pdd factor	Positive degree days correction factor	0.15 -0.9
Base Flow		1.94 cumec
Infiltration		90 mm per month (*Sakai et al. 2004*)

Flow Chart of PDD Model



Discharge Calculation

Discharge in each zone is calculated as

$$Q = Q1 + Q2 + Q3$$

Where

Q1= Snow and Ice melt from glacier and rock

Q2= Ice melt under debris

Q3= Effective rainfall

Calculation of Q1

Calculation of Ablation

Q1= PDD * Degree Day factor

Calculation of PDD

PDD= Y/N * No. of days in Month

Calculation of Positive degree-day sum:

It is calculated from monthly mean temperature as described by Braithwaite (1985).

Calculation of Q2

Ice melt under Debris:

Q2 = Remaining PDD * Degree Day Factor for Ice * Debris Properties

Debris Properties = Ratio of degree day factor for debris covered ice to degree day factor for bare ice
(*Kayastha et al. 2000b)*

Calculation of Q3

- **Precipitation was separated into snow and rain**

if temp > 3.6 ^{o}C then ppt = rain

if temp < 0 ^{o}C then ppt = Snow

If 3.6 ^{o}C ≤ temp ≥ 0 ^{o}C then ppt = both snow and rain

Potential Evapo-transpiration:

PET = 2.54 * K * Ph * t (^{o}F) / 100 (Blanney- Criddle formula)

K=empirical coefficient

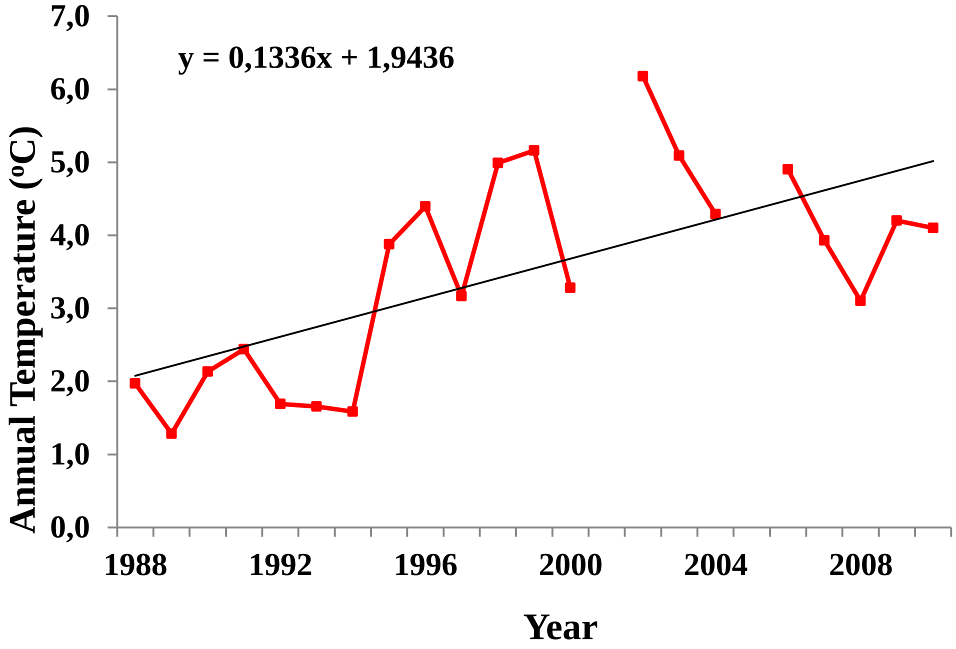
Ph = monthly percent of annual day time hours

t= temperature in Fahrenheit

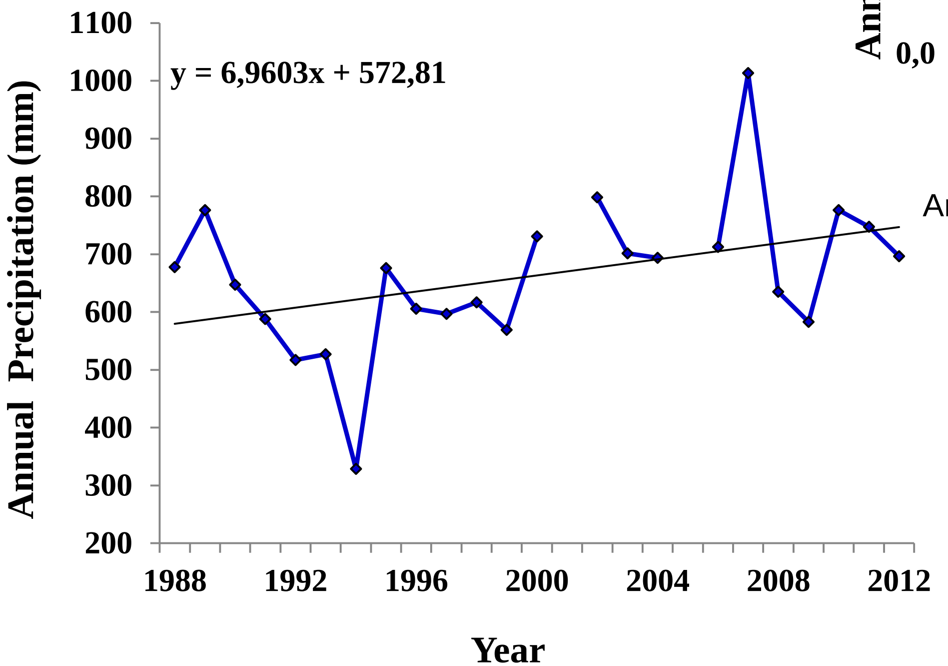
Q3= Rain – Infiltration – PET+ Base Flow

Results

Climate Trend Analysis

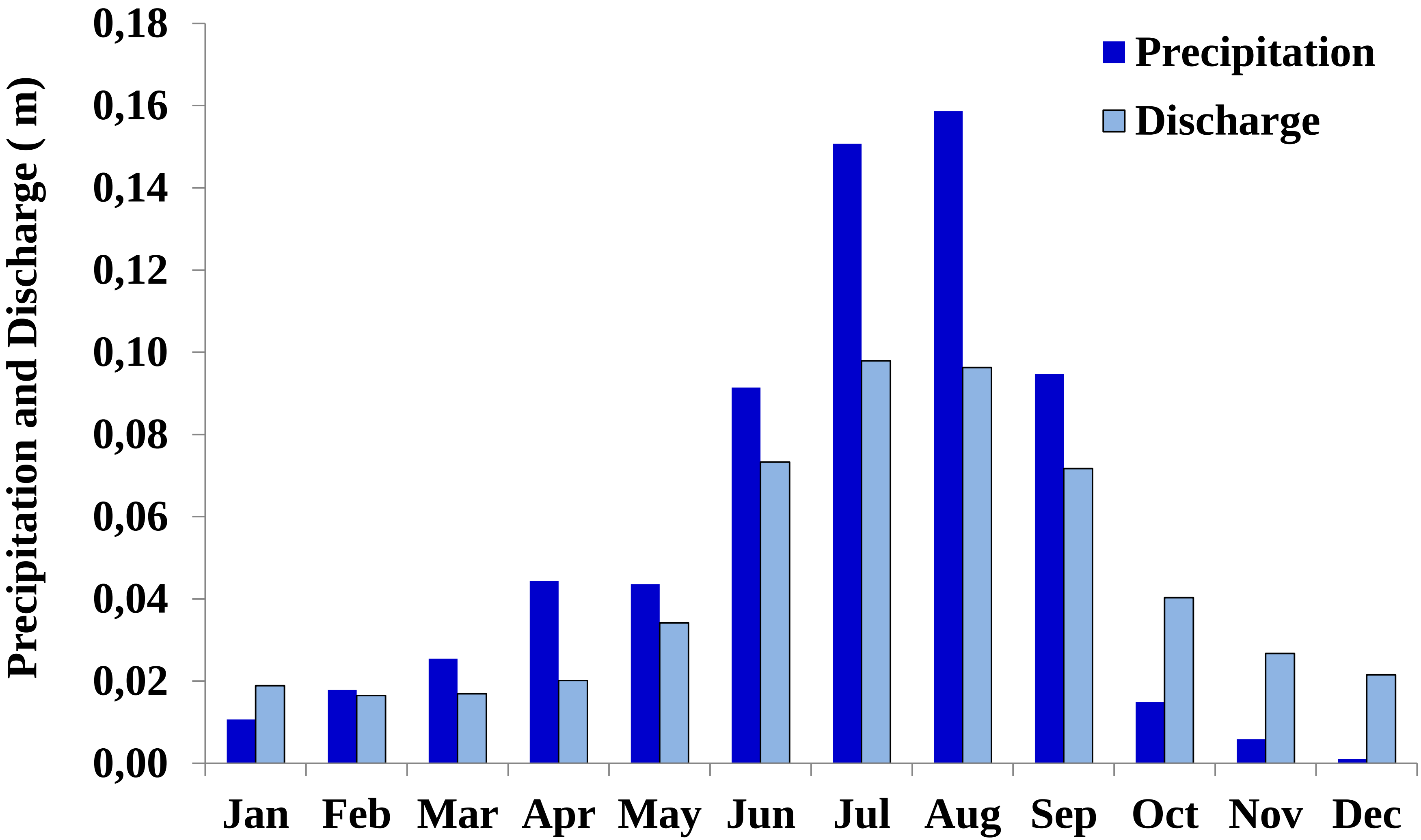


Annual temperature trend (1988-2010) of Langtang River basin.

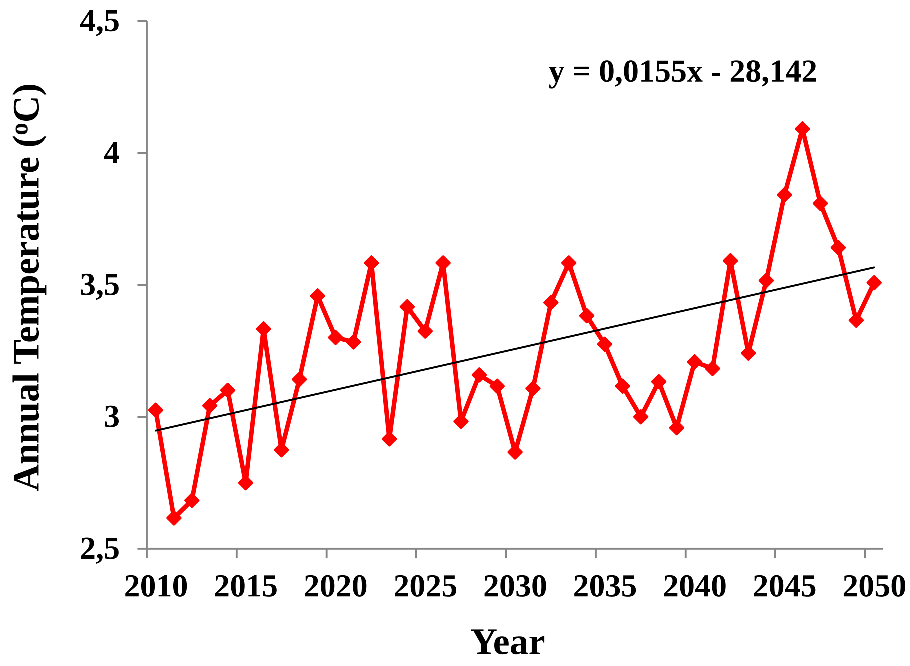


Annual Precipitation trend (1988-2012) of Langtang River basin.

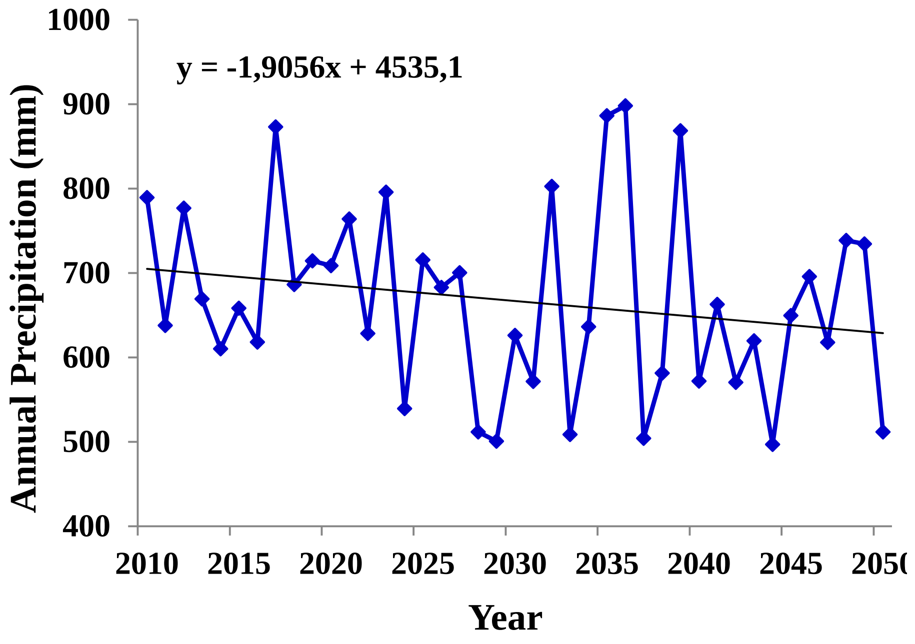
Observed precipitation and discharge of the Langtang River basin (1993 – 2006)



Future Climatic Trend Analysis



Projected annual temperature of Langtang River Basin (2010- 2050)



Projected annual precipitation of Langtang River basin (2010- 2050)

Quality Assessment
Model Accuracy

Goodness of fit (R^2)
Nash & Sutcliffe

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Q_i - Q_i^{'})^2}{\sum_{i=1}^{n} (Q_i - \bar{Q})^2}$$

where;

Q_i : measured daily discharge

$Q_i^{'}$: computed daily discharge

$\bar{Q}$: average measured discharge of the season under study

n : number of daily discharge values

Volume Difference

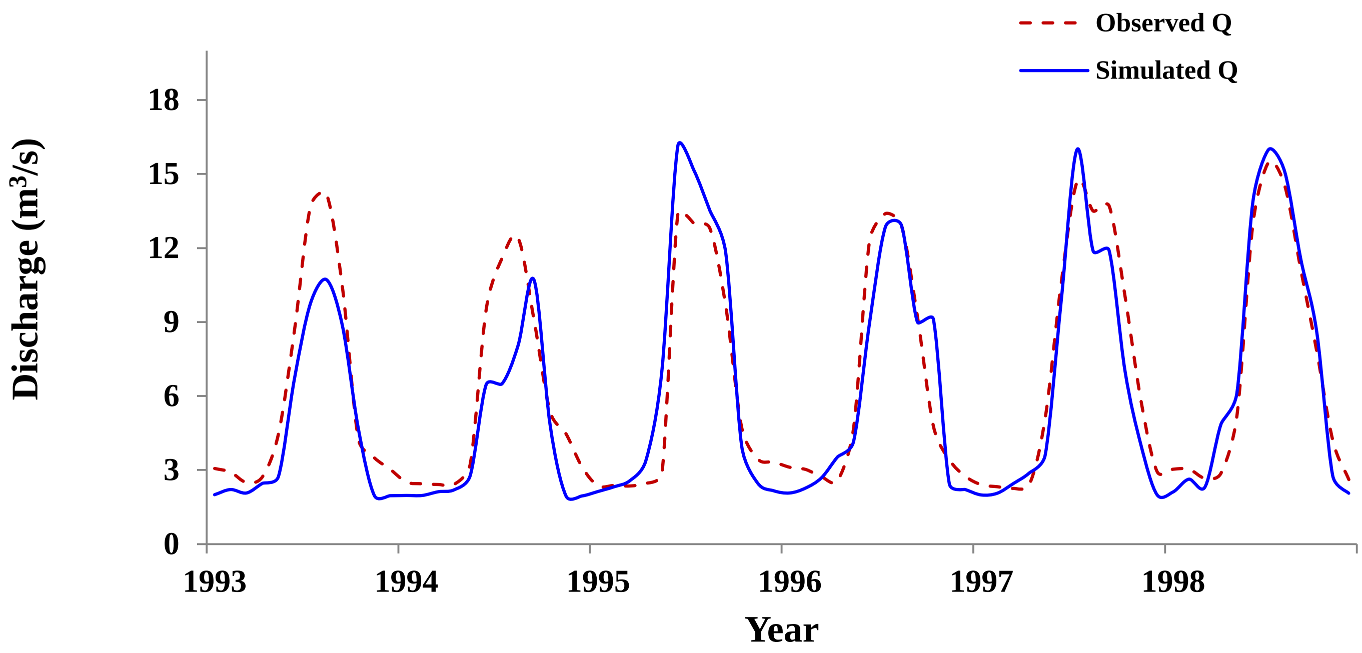
$$D_V[\%] = \frac{V - V^{'}}{V} \cdot 100$$

V : measured runoff volume

$V^{'}$: simulated/forcasted runoff volume

Model Calibration

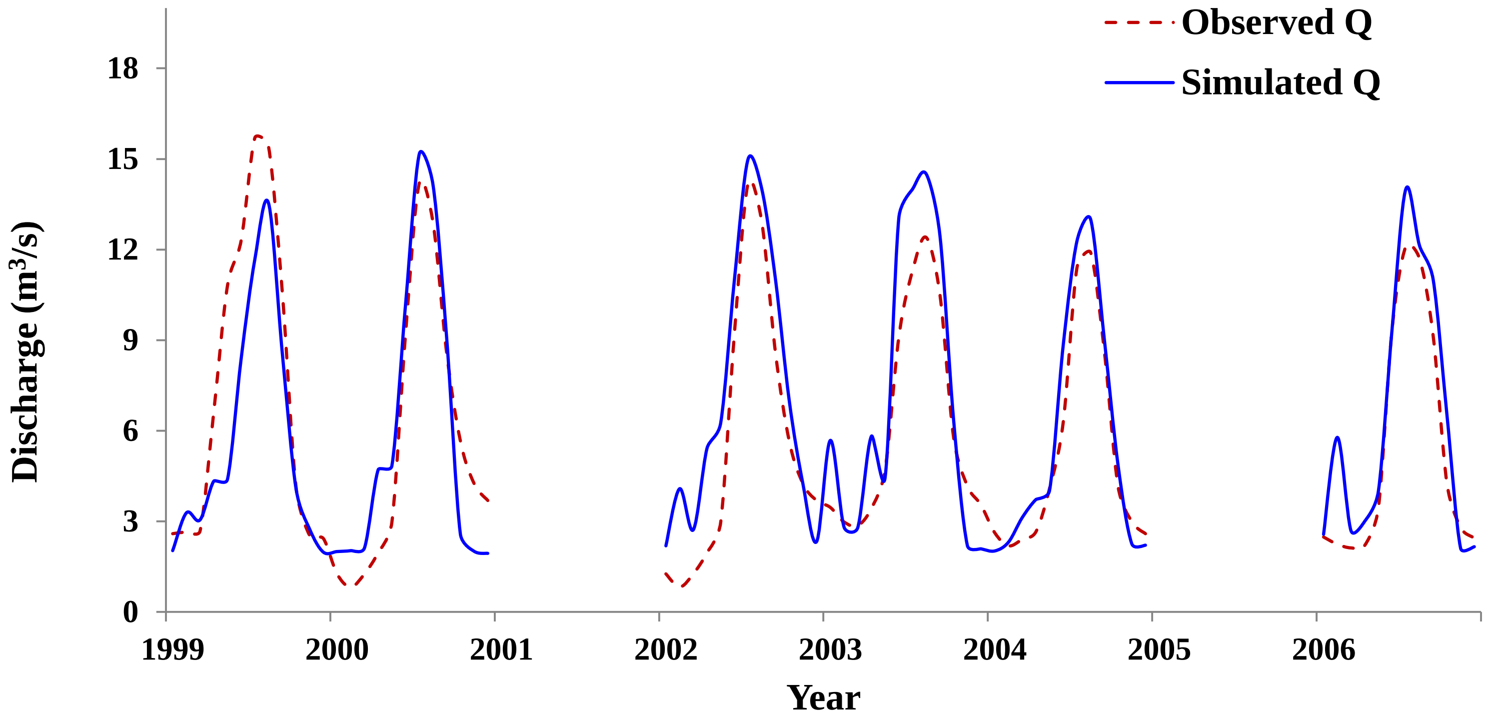
Model calibration was carried out from 1993 – 1998 AD



Nash-Sutciff = 0.85
Volume Difference = 7.5%

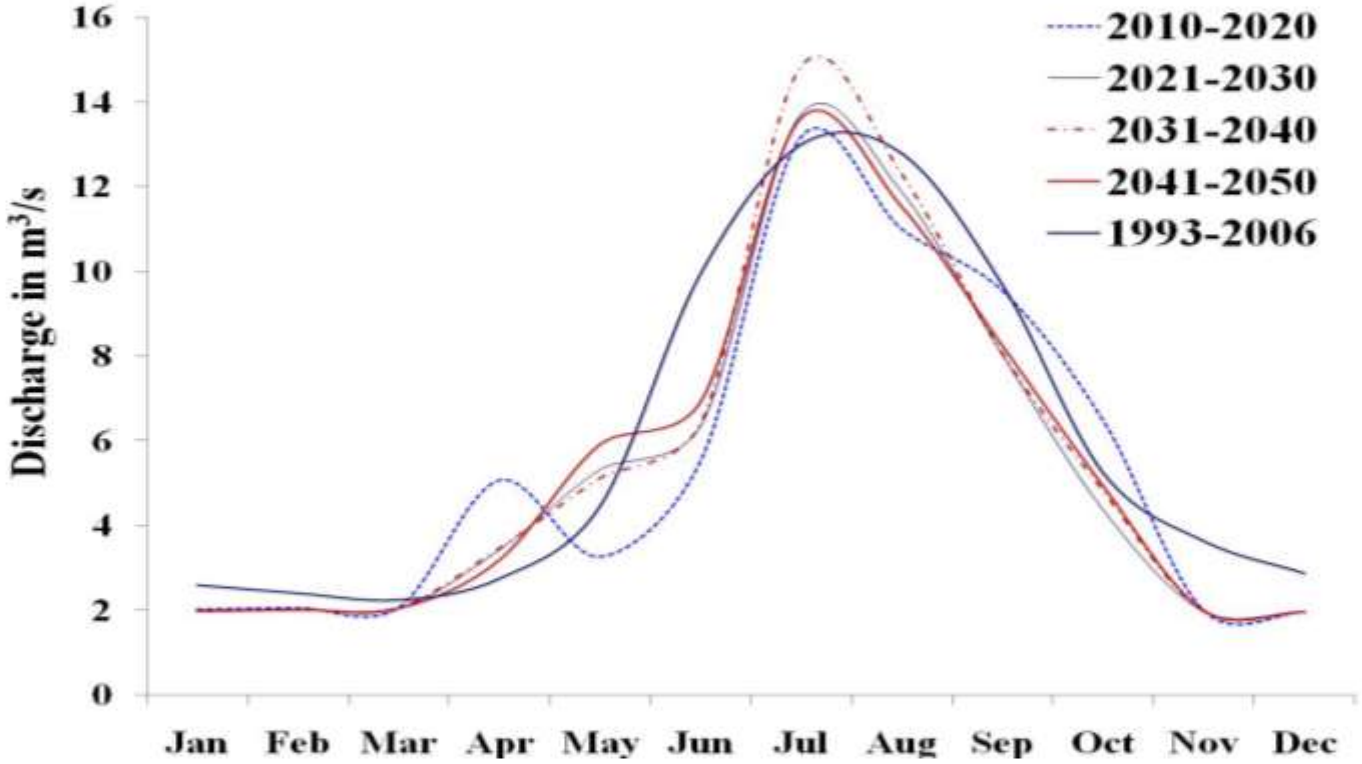
Model Validation

Model validation was carried out from 1999 – 2006 AD

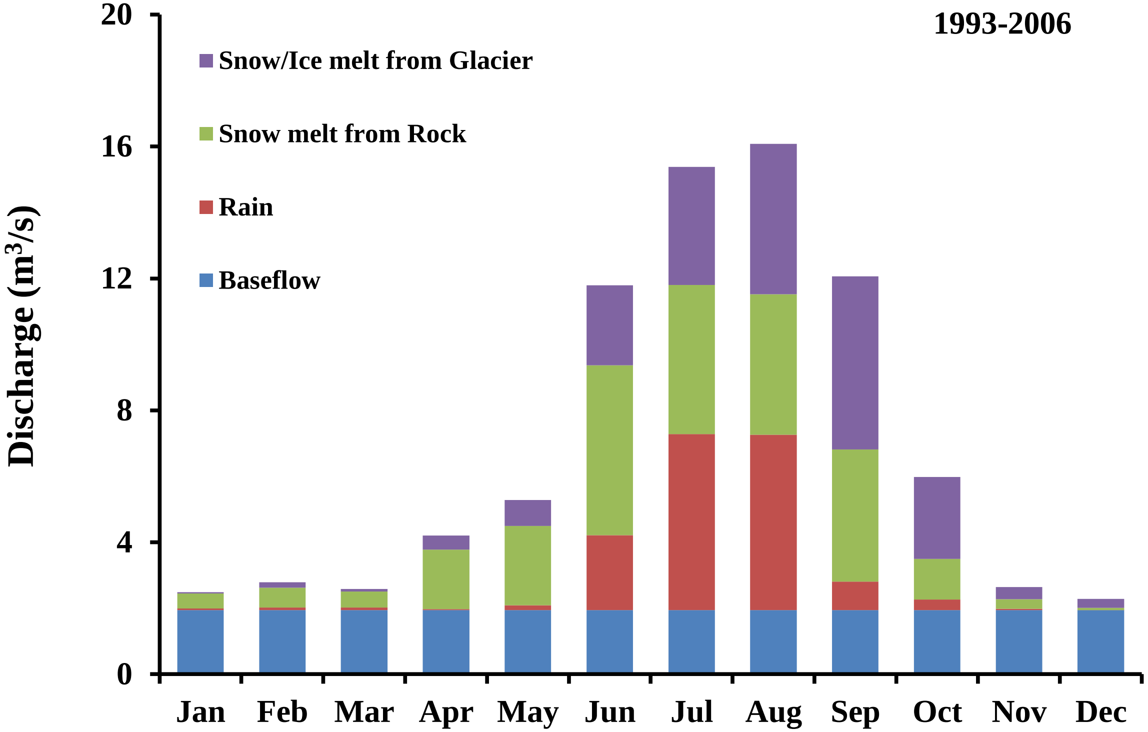


Nash-Sutciff = 0.80
Volume Difference = -7.3%

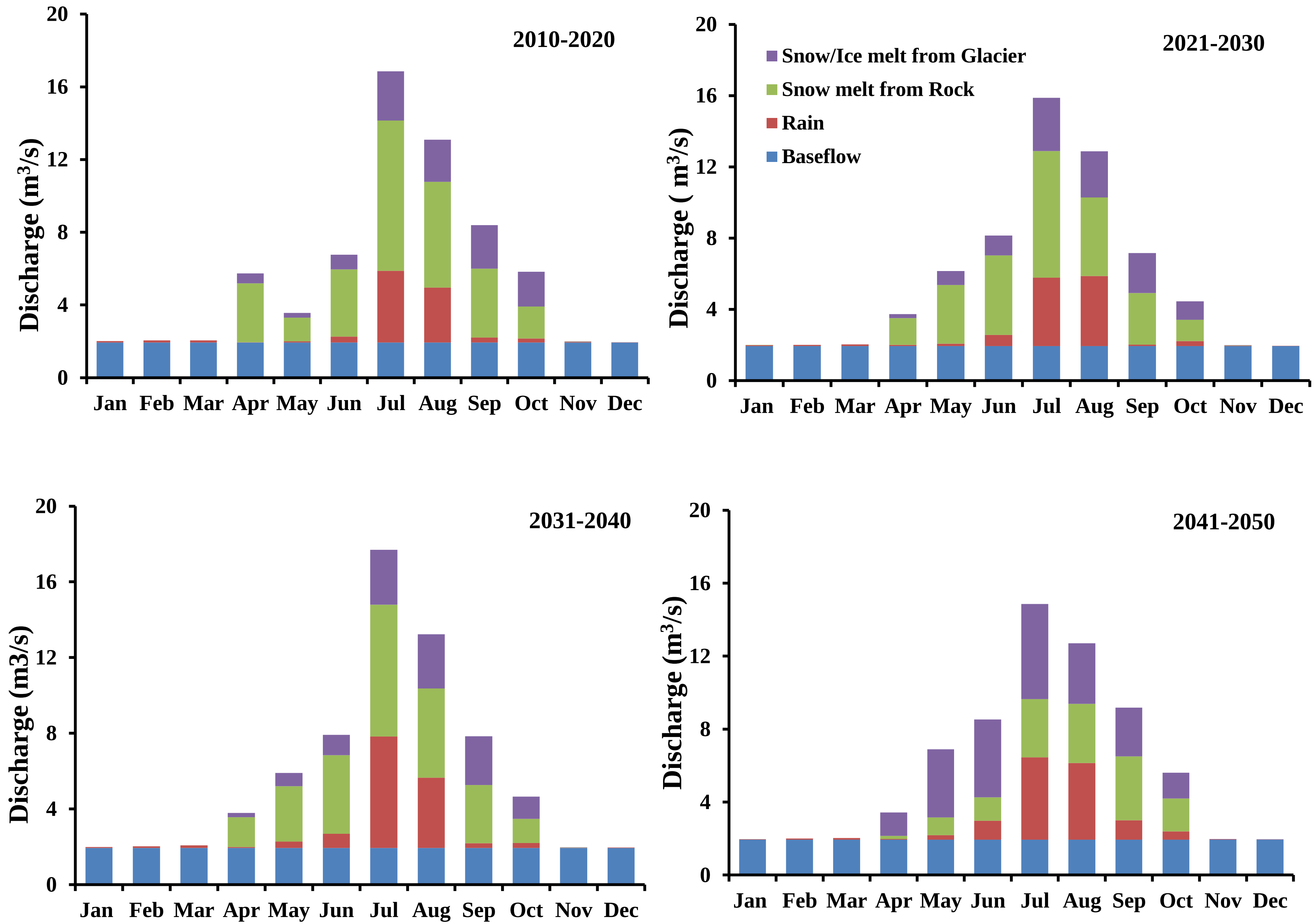
Comparison of projected decadal hydrographs with the observed hydrograph (1993 – 2006)



Snow/Ice Contribution in the total discharge



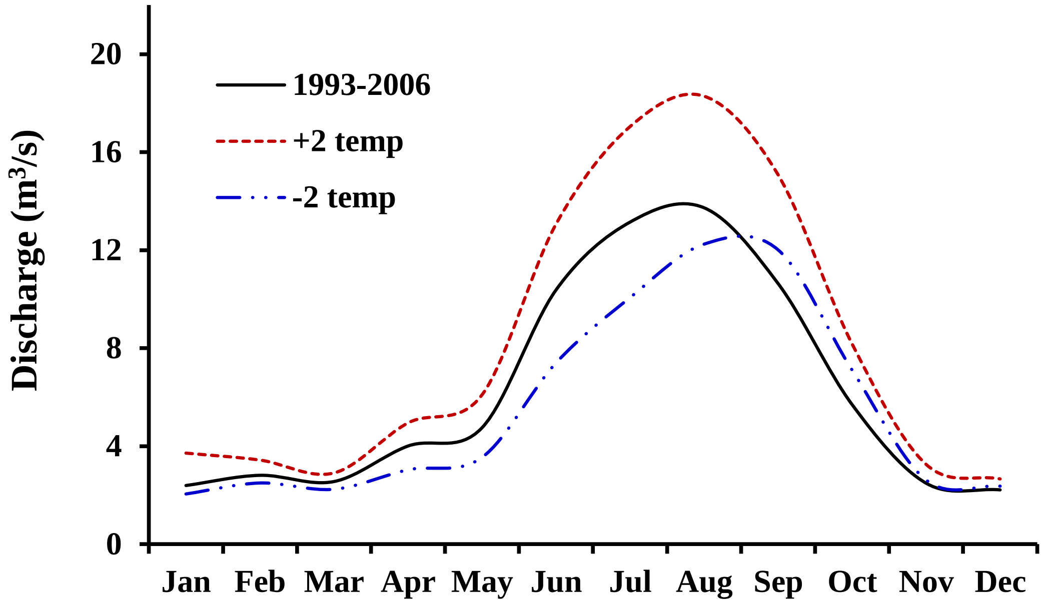
Time Period	Snow/Ice Contribution (%)
1993 - 2006	72
2010 - 2020	55
2021 - 2030	52
2031 - 2040	51
2041 - 2050	50

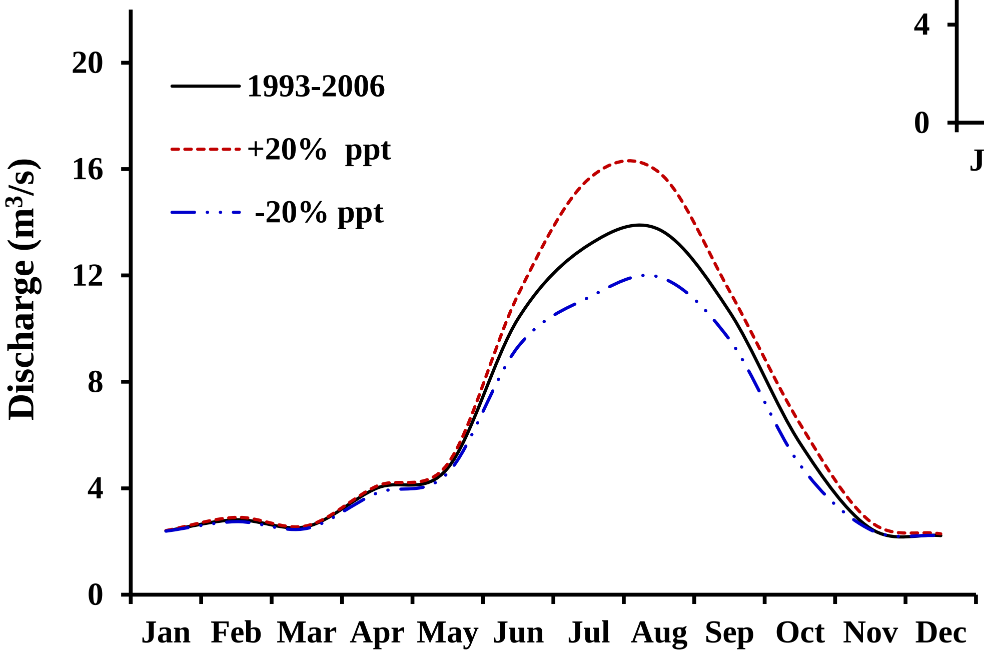

2010-2020
2021-2030
2031-2040
2041-2050
Snow/Ice melt from Glacier
Snow melt from Rock
Rain
Baseflow
Discharge (m3/s)
Discharge (m3/s)
Discharge (m3/s)
Discharge (m3/s)
0
4
8
12
16
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Sensitivity Analysis

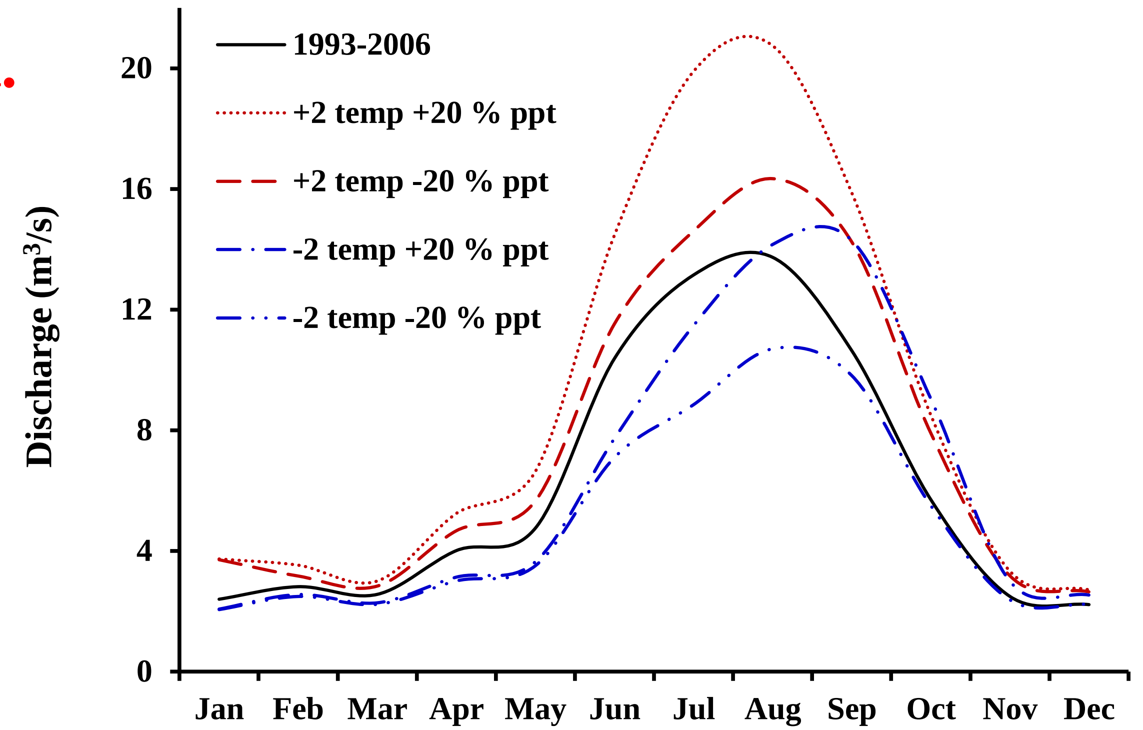
3 Parameters were selected for Sensitivity Analysis

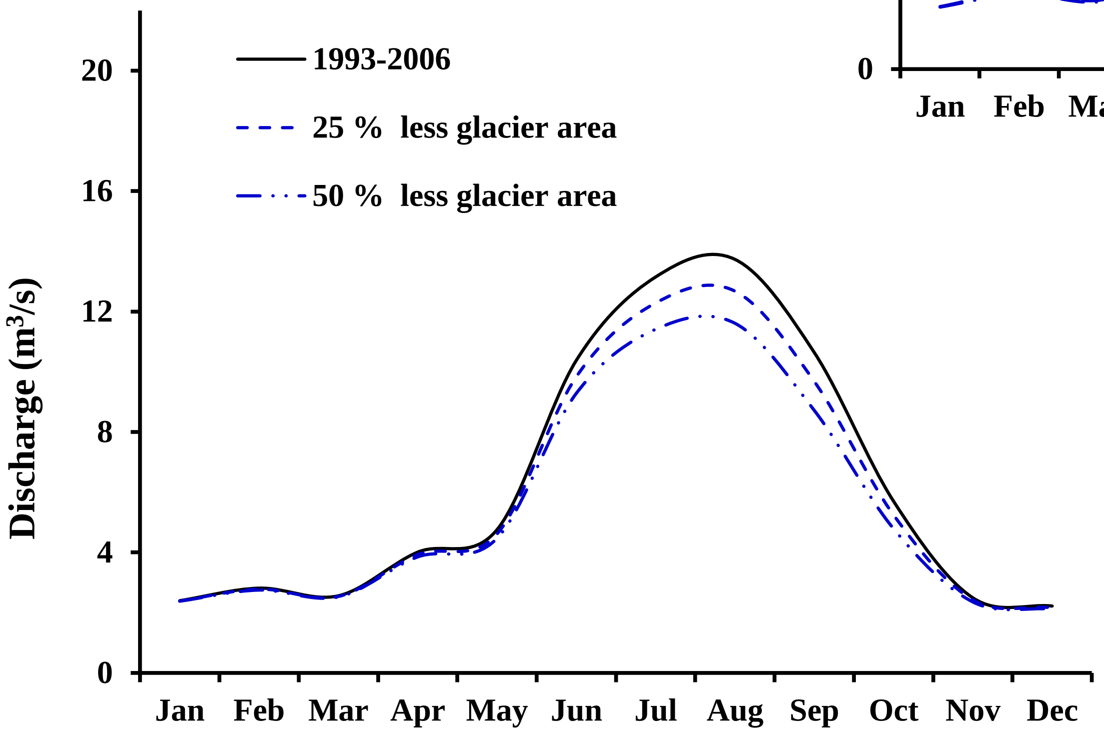
- Temperature
- Precipitation
- Glacier area





Sensitivity Analysis Cont.





Sensitivity Analysis Cont.

Parameters	Experiment	Change in discharge(%)
Temperature	+ 2 ^{o}C	+ 31.9
	- 2 ^{o}C	- 10.1
Precipitation	+20 %	+ 10.3
	- 20 %	- 9.7
Glacier area	- 25 %	- 5.7
	- 50 %	- 11.4
Temperature and Precipitation	+ 2 ^{o}C temp + 20 % ppt	+ 43.9
	+ 2 ^{o}C temp - 20 % ppt	+ 20.9
	- 2 ^{o}C temp + 20 % ppt	+ 1.4
	- 2 ^{o}C temp - 20 % ppt	- 20.9

Conclusions

- **The PDD model is used to estimate discharge from the Langtang River basin**
- **Calibration and validation of the model is performed with Nash-Sutcliffe value of 0.85 and 0.80 respectively**
- **The peak discharge is calculated as 21.5 m^3/s in July 2048.**
- **Future water scenarios (2010- 2050) from this model suggest that the discharge will increase in the premonsoon and the magnitude of peak discharge will be in the month of July.**
- **Contribution of snow and ice melt to total discharge will decrease by 20 % from the average condition of 1993 to 2006 in 2050.**
- **Temperature was found to be more sensitive than other parameters**
- **These results can help the water resource management planners to develop sustainable policies and plans in the Himalayan region**


Thank You