Simulation of sedimentation rates using the SWAT model

A case study of the Tarbela Dam, Upper Indus Basin

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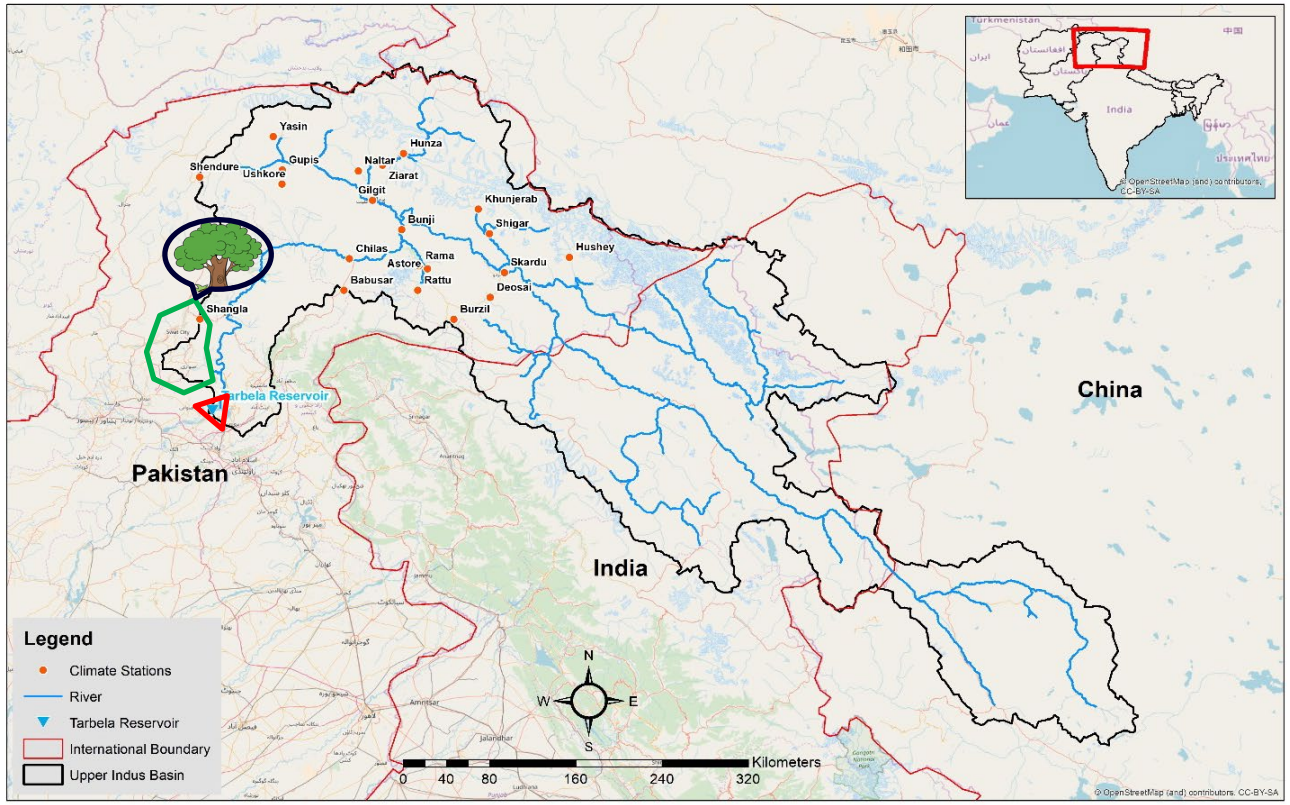
Outline of the Presentation

- Introduction
- Problem statement & Research objectives
- Methodology
  - Selection of climate data (precipitation and temperature)
  - Model setup for calibration and validation of hydrology and sediment
- Results of Calibration and Validation.
- Land use changes scenarios
- Conclusion
- Limitations
- Recommendations

Problem statement

The main problems in the Upper Indus Basin are described as under:

- Soil erosion and sediment transport rate
- Unknown contribution of sediment from sub-basins of the catchment
- Impact of Land use/cover (LULC) changes on discharge and sediment yield
- Optimization of Billion Tree Tsunami project.



Research Questions

Based on above issues, the questions requiring further research are listed below:

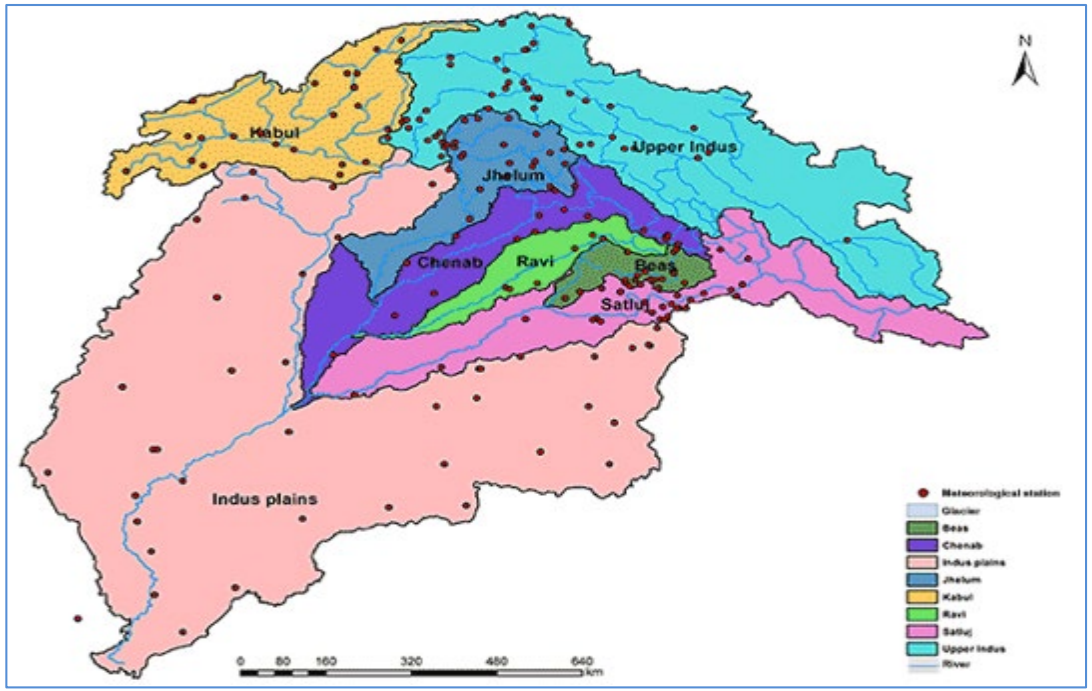
- What are the current sediment inputs to Tarbela Reservoir?
- What are current contributions of the major sub-basins in terms of sediment production in the Upper Indus Basin?
- What will be the effects of the Billion Tree Tsunami project on the water and sediment inputs to the Tarbela Reservoir?
- Can the Billion Tree Tsunami project be optimized by assessing priority areas?

Research Objectives

This research will focus on change of land use/cover of the basin and its impacts on the sediment yield of basin at the sub basin scale.

Study area

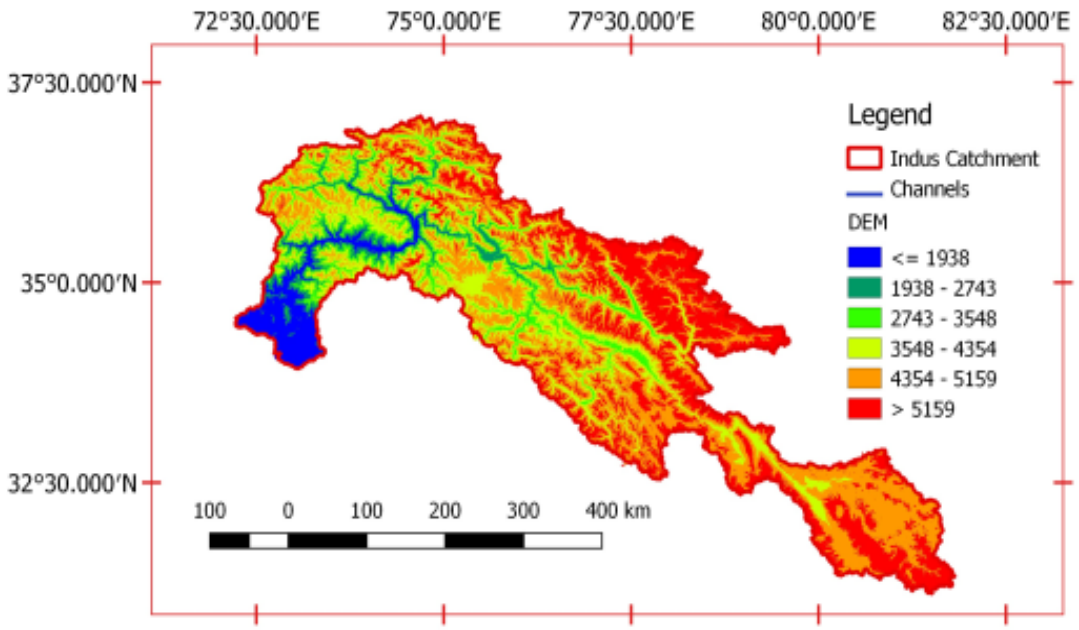
- The Indus River originates from Tibetan Plateau of china.
- The Indus River is a trans-boundary river which originates from China and passes through India and then Pakistan having length 1126 km upto Tarbela Reservoir.
- The area of Upper Indus Basin upto Tarbela dam is 169,333 km^2

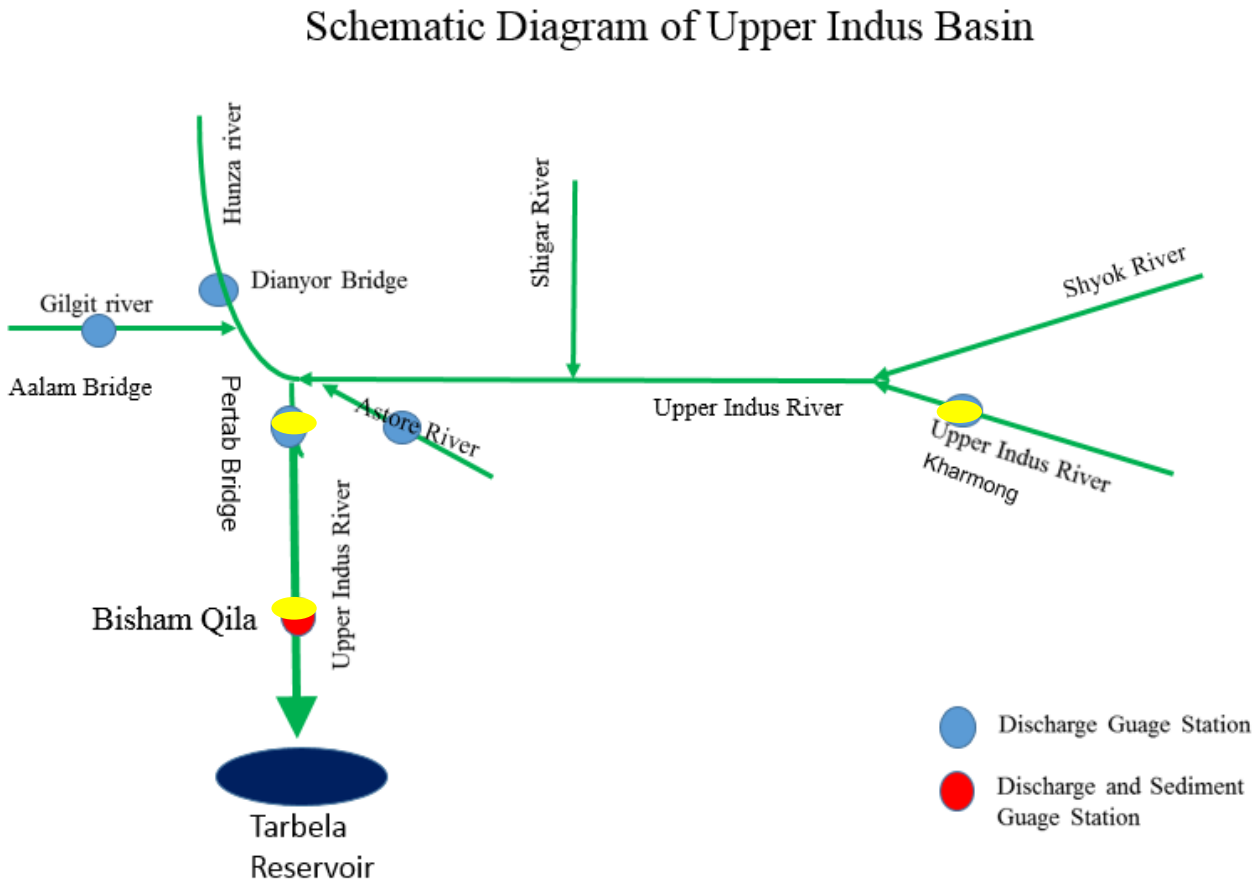


The Tarbela Reservoir is the downstream boundary of the Upper Indus Basin.

Topography

- The elevation in the Upper Indus Basin varies from 550 m to 8200 m (meter above sea level)





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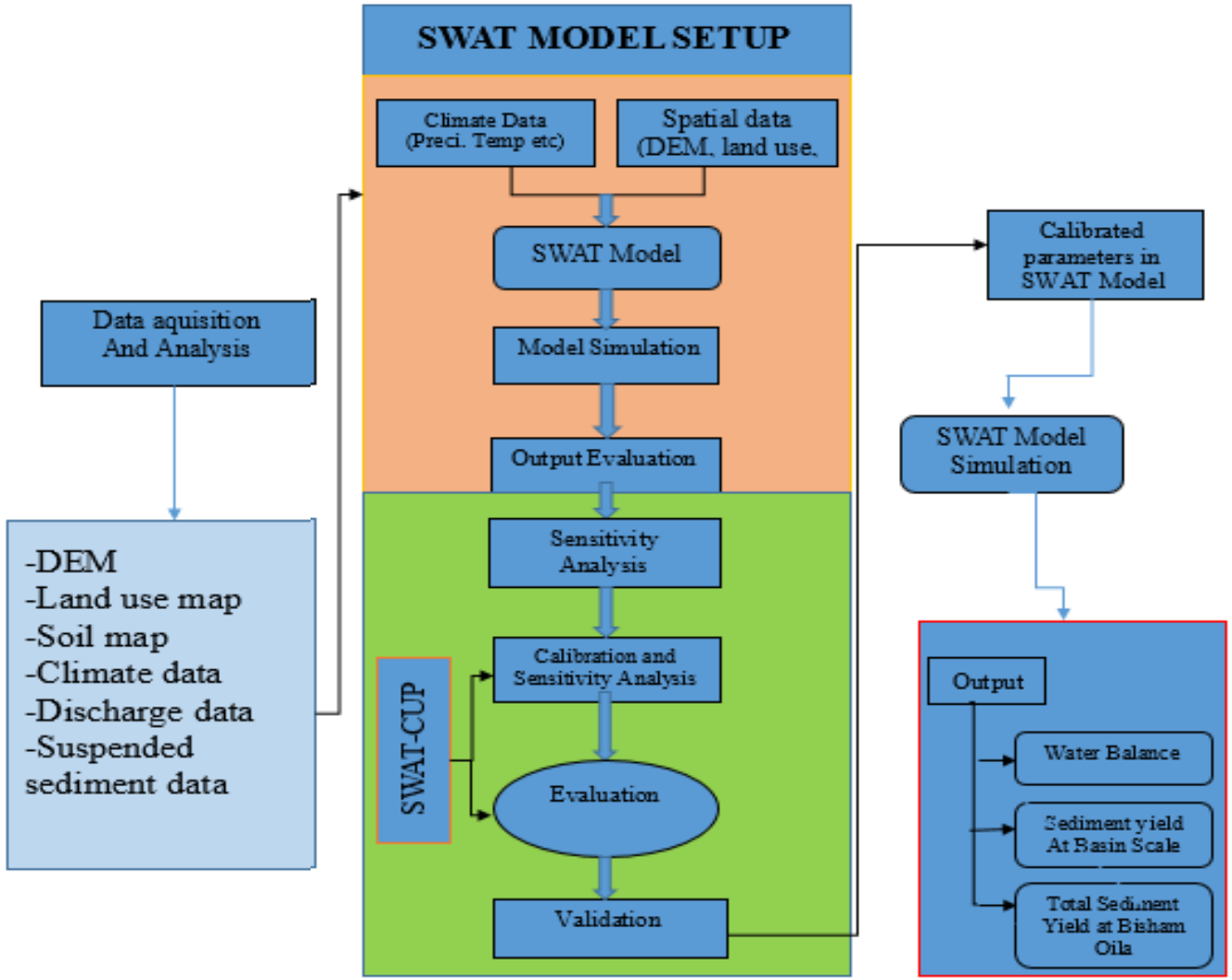
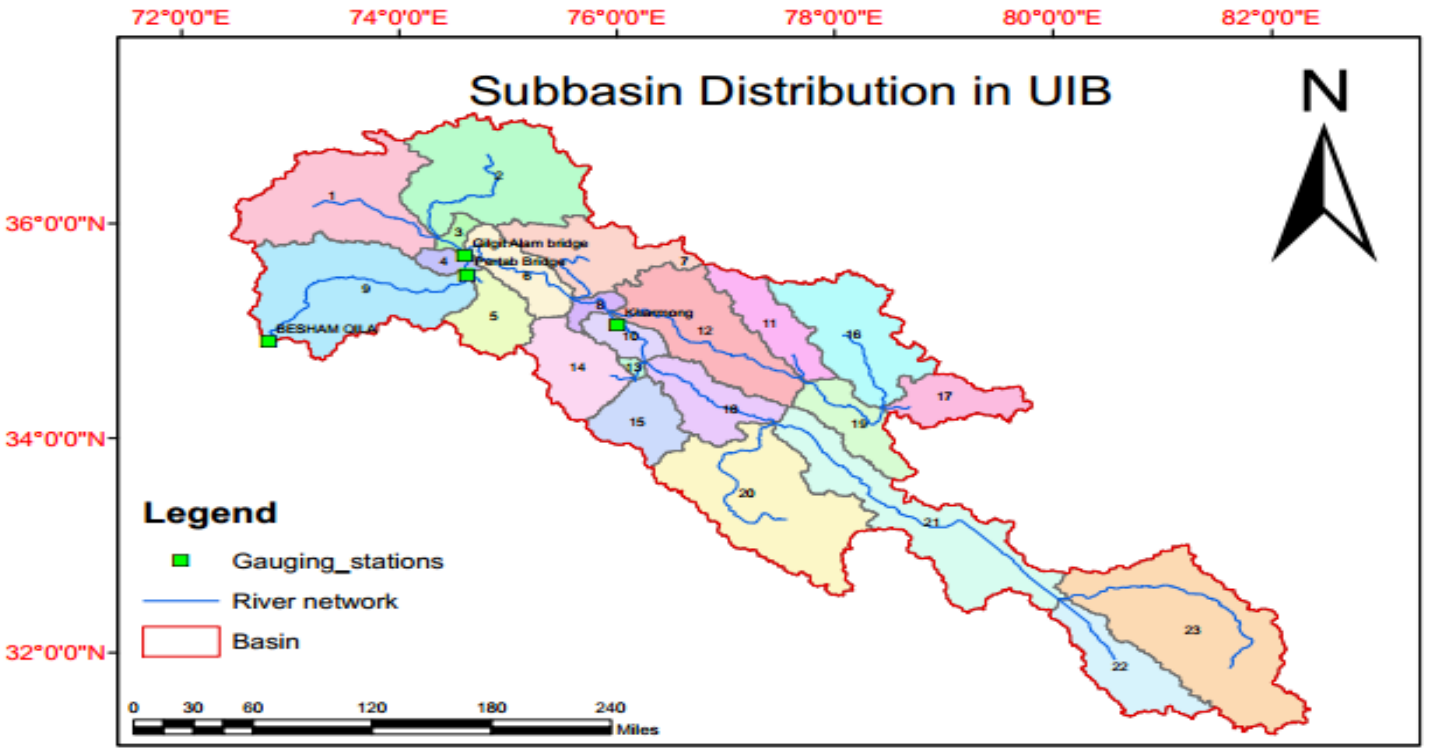
Methodology



Catchment delineation

- Model
- No. of sub basins- 23



Sub basin map

Land Use map

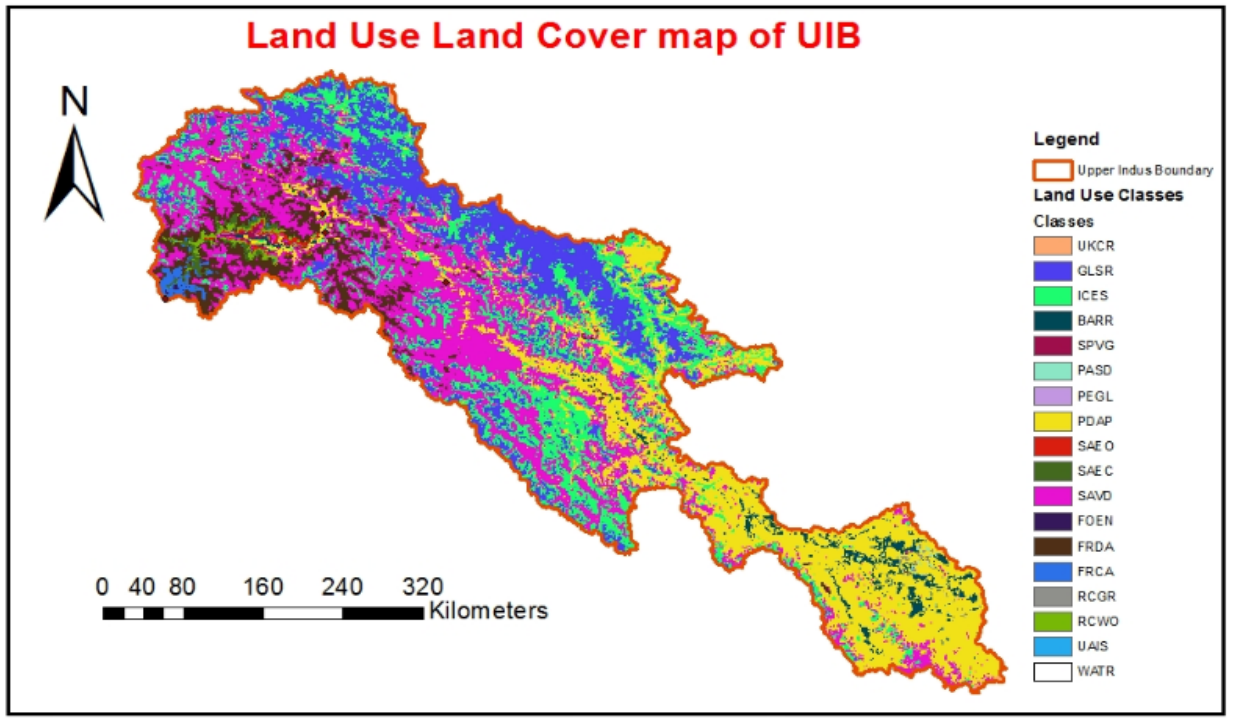
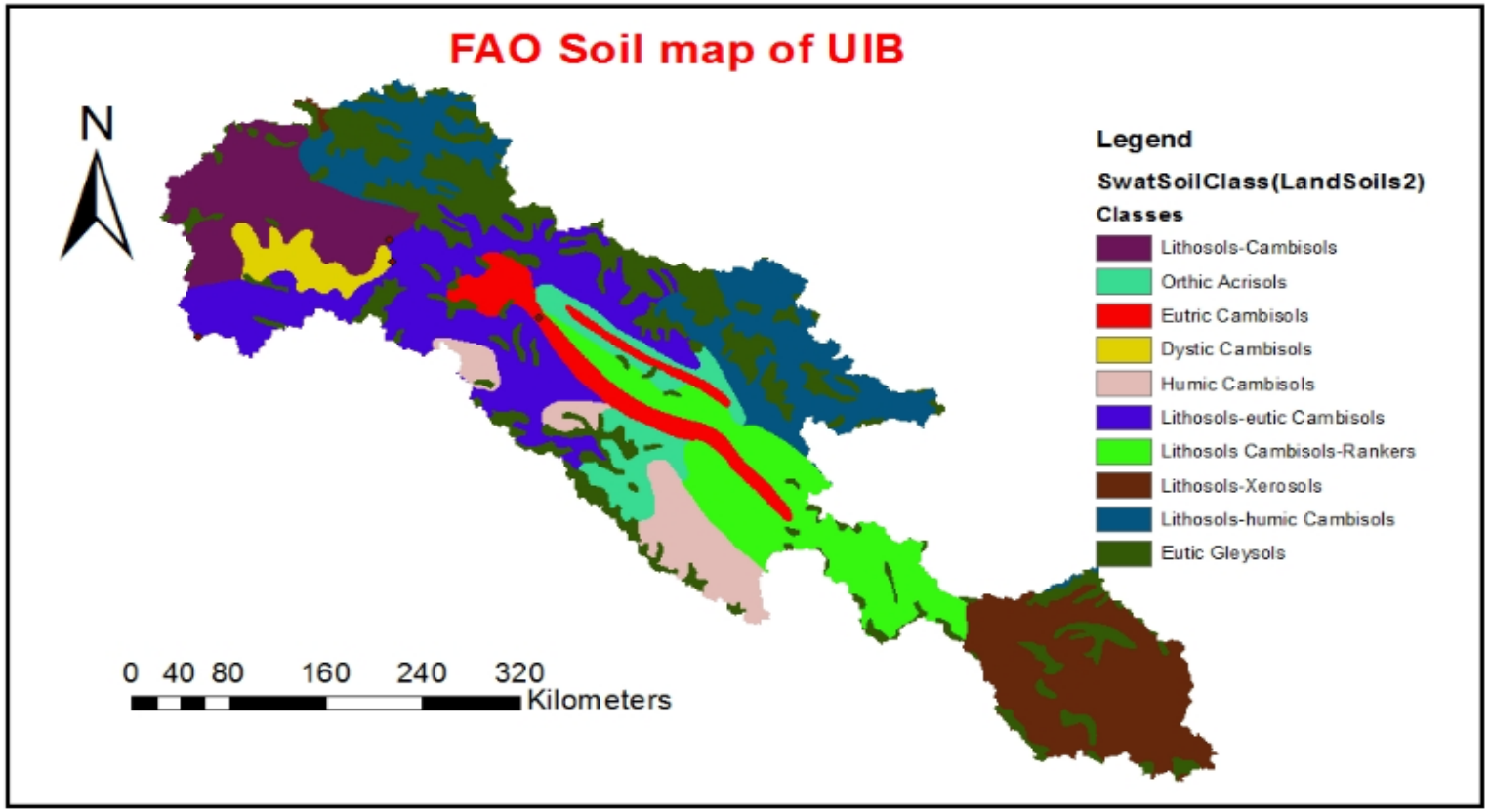


Table 3-1: Land use /Cover Classes in UIB (Cheema et al. 2010).

LandUse	Description	Area % in the Watershed
GLSR	Glacier	15.77
ICES	Snow or Ice	19.11
BARR	Barren land	2.14
SPVG	Sparsely vegetated	0.26
PASD	Pasture deciduous	0.06
PEGL	Pasture evergreen lowland	0.02
PDAP	Pasture deciduous alpine	23.07
SAEO	Savana evergreen open	0.26
SAEC	Savana evergreen closed	0.55
SAVD	Savana deciduous	28.67
FOEN	Evergreen needle leaf forest	0.03
FRDA	Forest deciduous alpine	6.3
FRCA	Forest-cropland alpine	0.58
RCGR	Rain fed crop general	0.17
RCWO	rain fed crop and wood	0.51
WATR	water	0.02

Source: Land use map by Cheema (2010)

Soil map

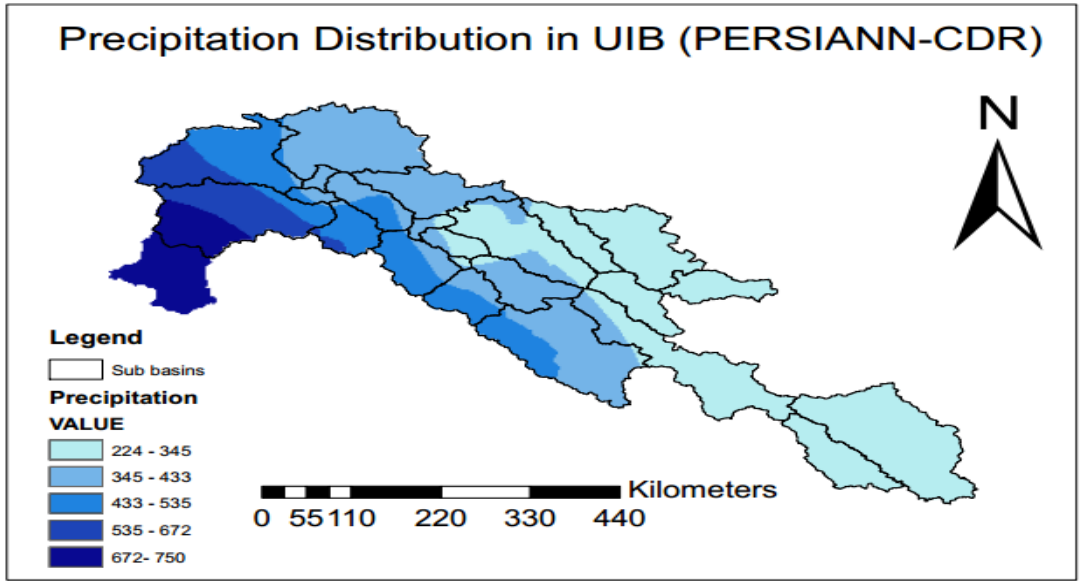


Source: FAO soil map used which is freely available on water base project website and having spatial resolution of 1 km x 1 km.

- Slope classification - 3 class 0-8, 8-30, and 30-99 percent of slope

Precipitation data

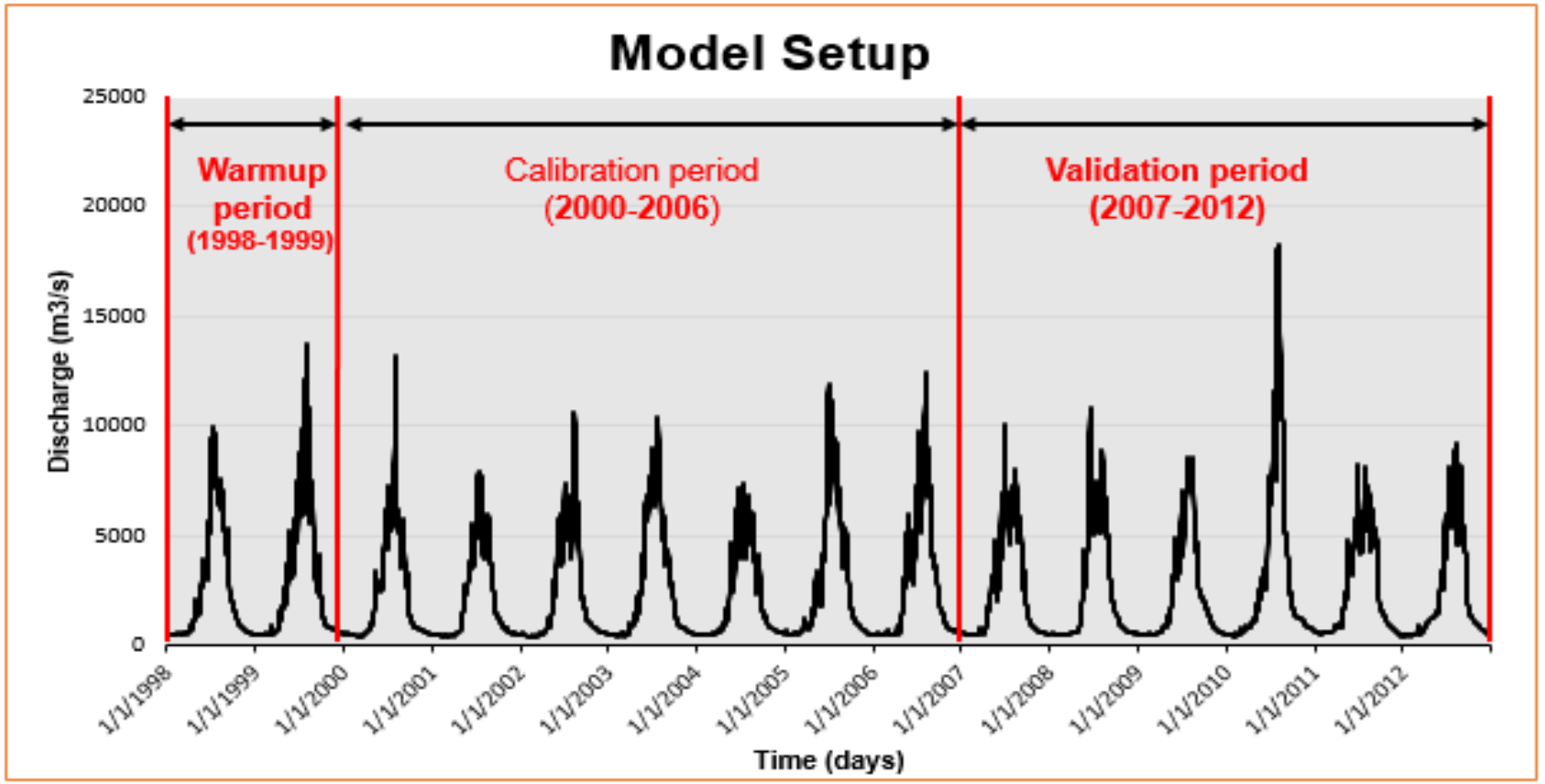
Parameter	TRMM	PERSIANN-CDR	CFSR
	mm/year	mm/year	mm/year
Overall mean	298.2	415	724
STDEV	75.1	94.1	328
Min	180.1	207.6	235
Max	462.5	631.3	1529



Temperature data

Observed + CFSR (Climate forecast system re analysis)

Model Setup for calibration & validation



Discharge data obtained from WAPDA

Calibration parameters for hydrology

Sr No.	Parameters	Best fitted values	Input range for last Iteration	
			Min	Max
1	r__SOL_AWC().sol	-0.68	-0.69	-0.52
2	v__GWQMN.gw	781.62	766.98	846.99
3	v__SMTMP.bsn	-0.02	-0.89	0.15
4	v__GW_DELAY.gw	18.82	17.23	19.09
5	v__SMFMX.bsn	7.41	7.17	7.87
6	v__CH_K2.rte	47.81	35.82	50.60
7	a__CN2.mgt	-1.43	-1.56	-1.05
8	v__SNO50COV.bsn	0.63	0.61	0.63
9	v__GW_REVAP.gw	0.06	0.05	0.06
10	v__RCHRG_DP.gw	0.01	0.00	0.03
11	v__TIMP.bsn	0.26	0.24	0.31
12	v__SNOCOVMX.bsn	460.54	456.66	467.47
13	v__SURLAG.bsn	4.35	4.24	5.96
14	v__SFTMP.bsn	1.69	1.40	1.93
15	r__SOL_K().sol	0.70	0.67	0.78
16	v__ESCO.bsn	0.06	0.03	0.06
17	v__TLAPS.sub	-7.57	-8.03	-7.42
18	v__PLAPS.sub	114.71	110.11	123.68
19	v__CH_N2.rte	0.04	0.03	0.04
20	v__ALPHA_BF.gw	0.79	0.62	0.79
21	v__SMFMN.bsn	2.29	1.69	2.41
22	v__REVAPMN.gw	592.09	568.30	640.61

Results of Calibration and Validation for runoff

Monthly time scale:

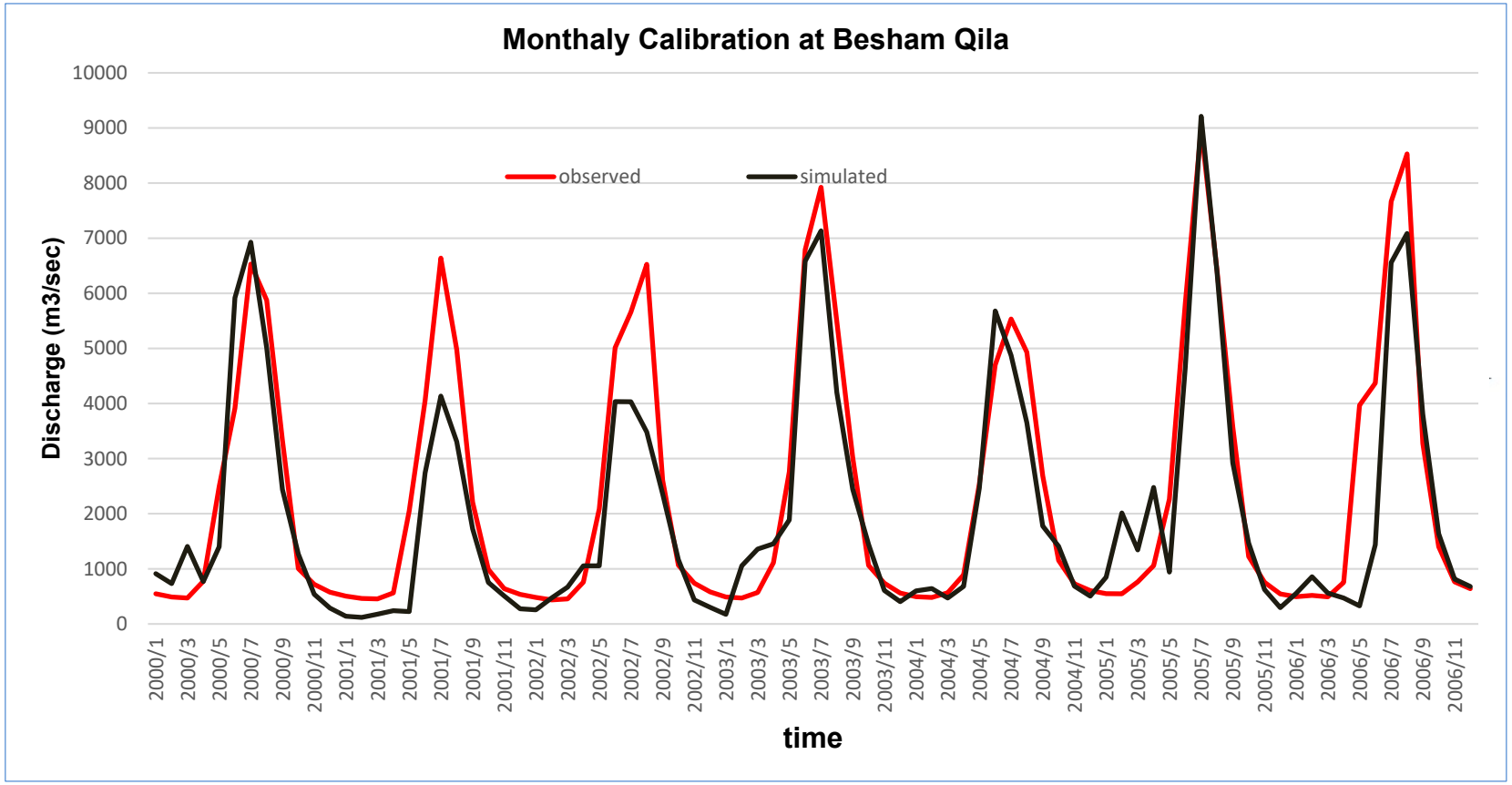
S.No.	Station name	Station code	Sub-basin outlet no.	Calibration			Validation		
				R^2	NSE	PBIAS	R^2	NSE	PBIAS
1	Kharmong	-	10	0.80	0.79	+5.70	0.70	0.55	-0.246
2	Pertab Bridge	3574760	4	0.84	0.80	-4.48	0.85	0.82	-10.4
3	Besham Qila	34729801	9	0.85	0.83	+11.3	0.84	0.81	+15.3

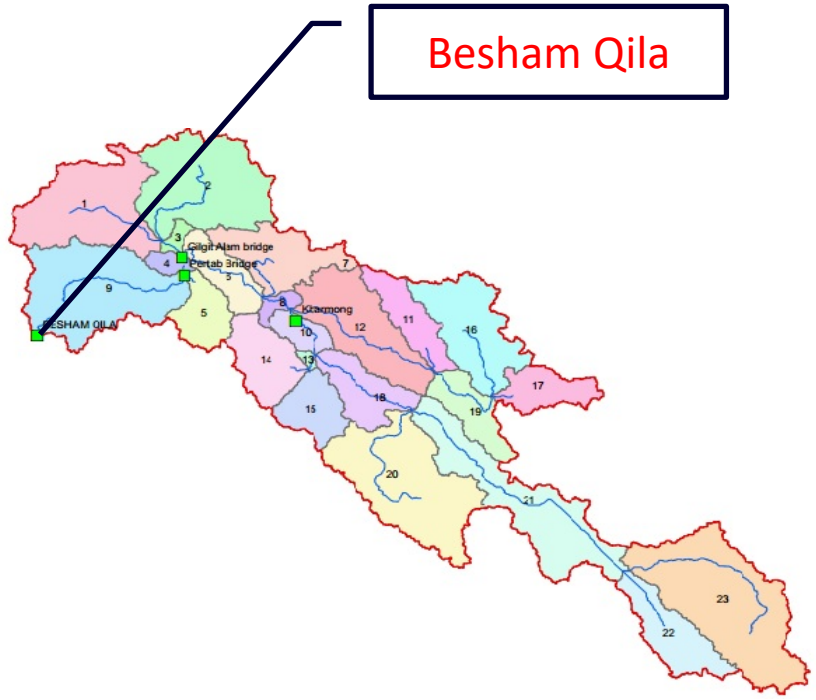
Daily time scale:

S.No.	Station name	Station code	Sub-basin outlet no.	Calibration			Validation		
				R^2	NSE	PBIAS	R^2	NSE	PBIAS
1	Besham Qila	34729801	9	0.76	0.70	+23	0.75	0.71	+14.4

Calibration at Besham Qila (Final Outlet station)

Observed	Simulated			
Average:2367.45	**2040.7**	R^2=0.85	NSE=0.83	PBIAS= +11.3





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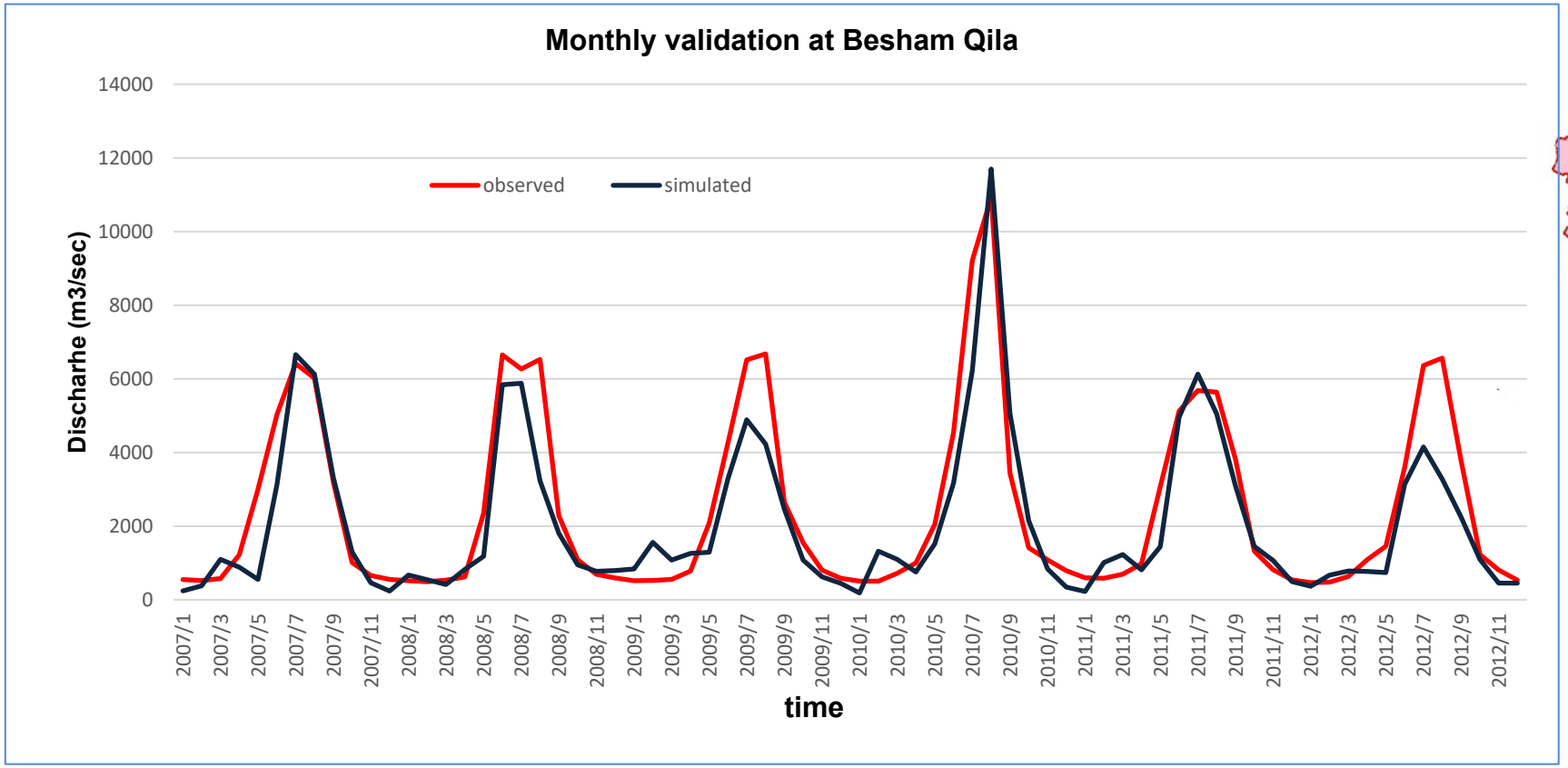
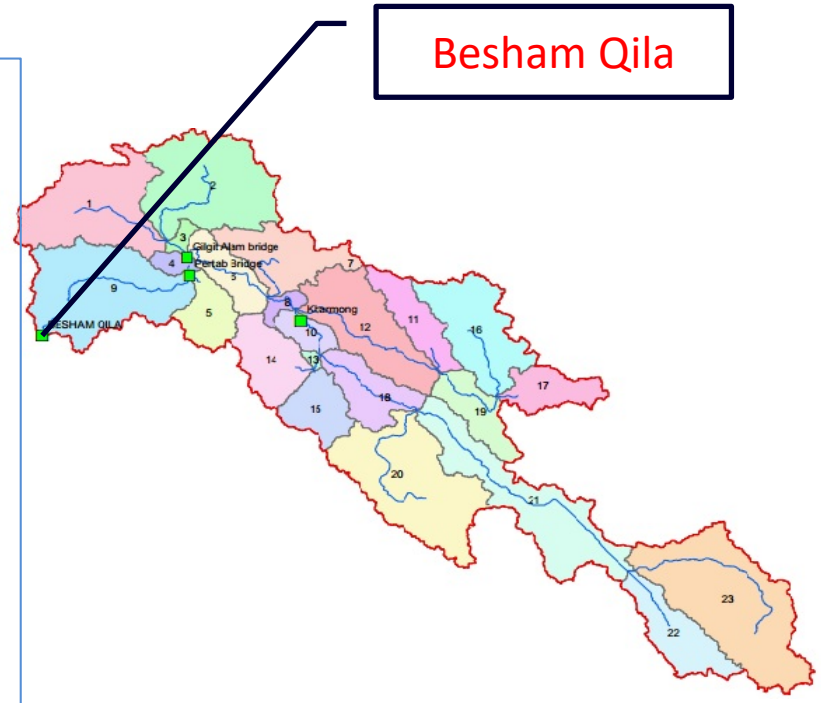
Validation at Besham Qila

Observed	Simulated			
Average:2457	2081	R^2=0.84	NSE=0.81	PBIAS= 15.3





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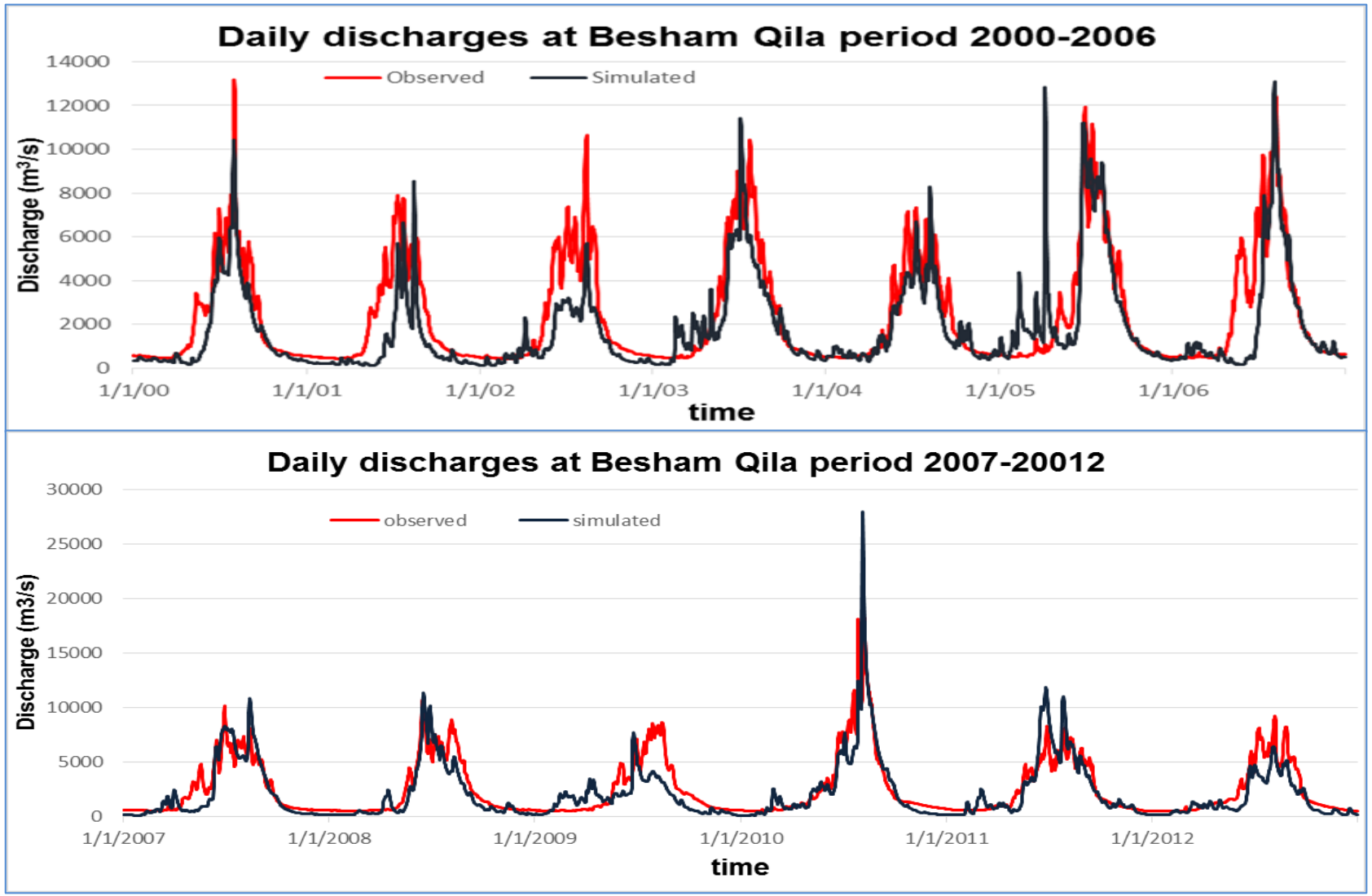
Calibration & validation at Besham Qila (Daily time scale)

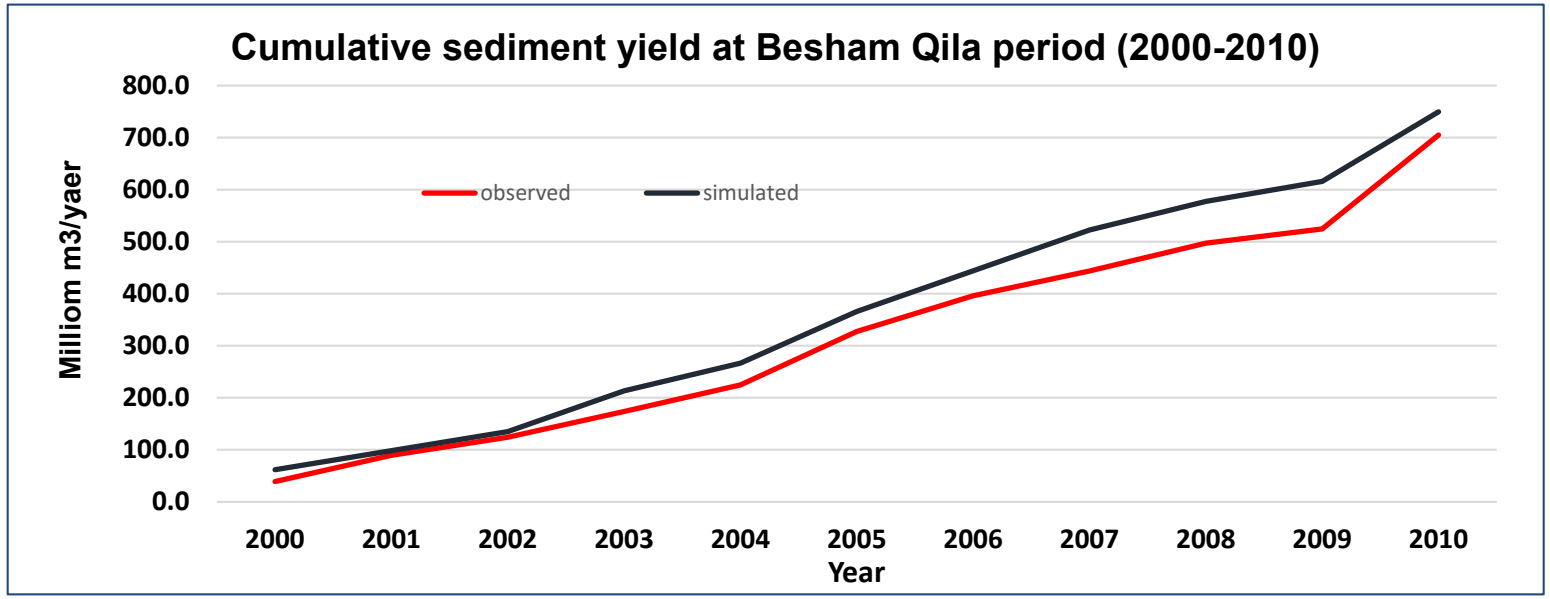


Calibration parameters for sediment

Sr No.	Parameters	Best fitted values	Input range for last Iteration	
			Min	Max
1	r__USLE_K.sol	-0.61	-0.70	-0.25
2	v__USLE_P.mgt	0.00429	0.00	0.15
3	v_CH_COV2.rte	0.0119	0	0.5
4	v_CH_COV1.rte	0.12	-0.05	0.6
5	v__SPCON.bsn	0.00471	0.0001	0.01
6	v__SPEXP.bsn	1.18	1.00	1.50

Results of Calibration and Validation for sediment on Monthly scale

S.No.	Station name	Station code	Sub-basin outlet no.	Calibration			Validation		
				R^2	NSE	PBIAS	R^2	NSE	PBIAS
1	Besham Qila	34729801	23	0.86	0.84	-12.4	0.88	0.85	+1.14



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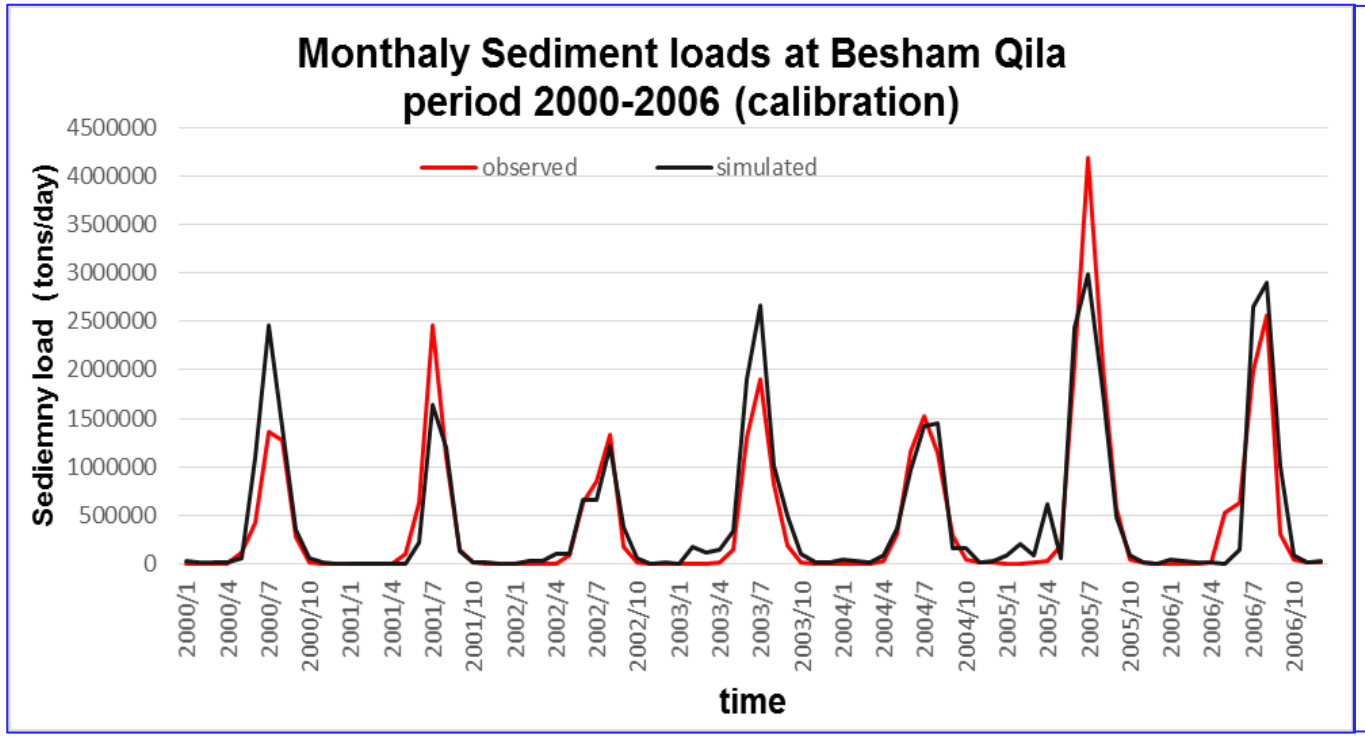
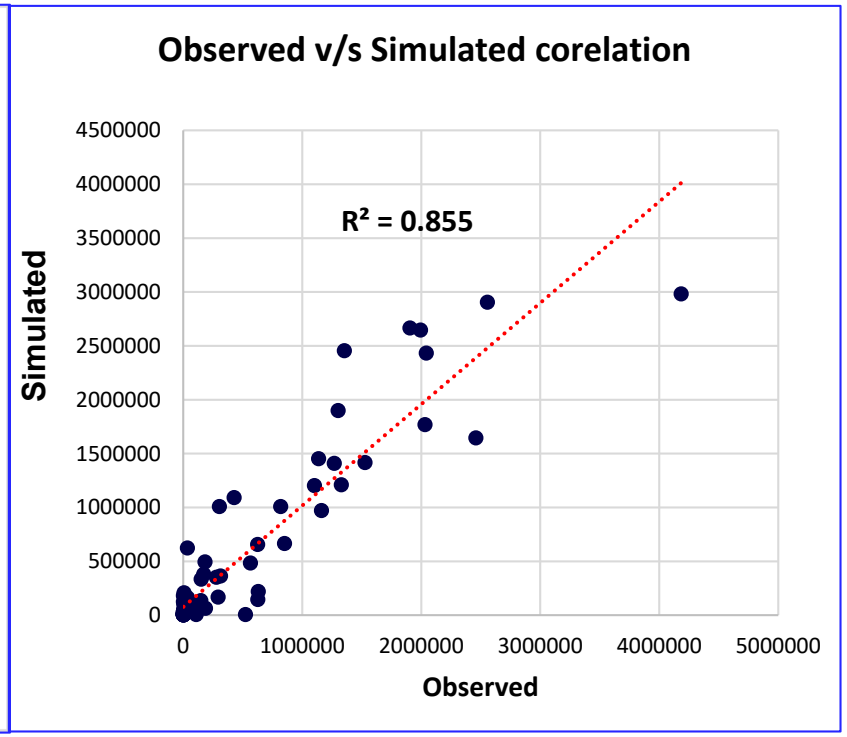
Sediment calibration at Besham Qila

Observed **Simulated**
Average: 419618 tonnes **470558 tonnes** NSE=0.84 PBIAS= - 12.4





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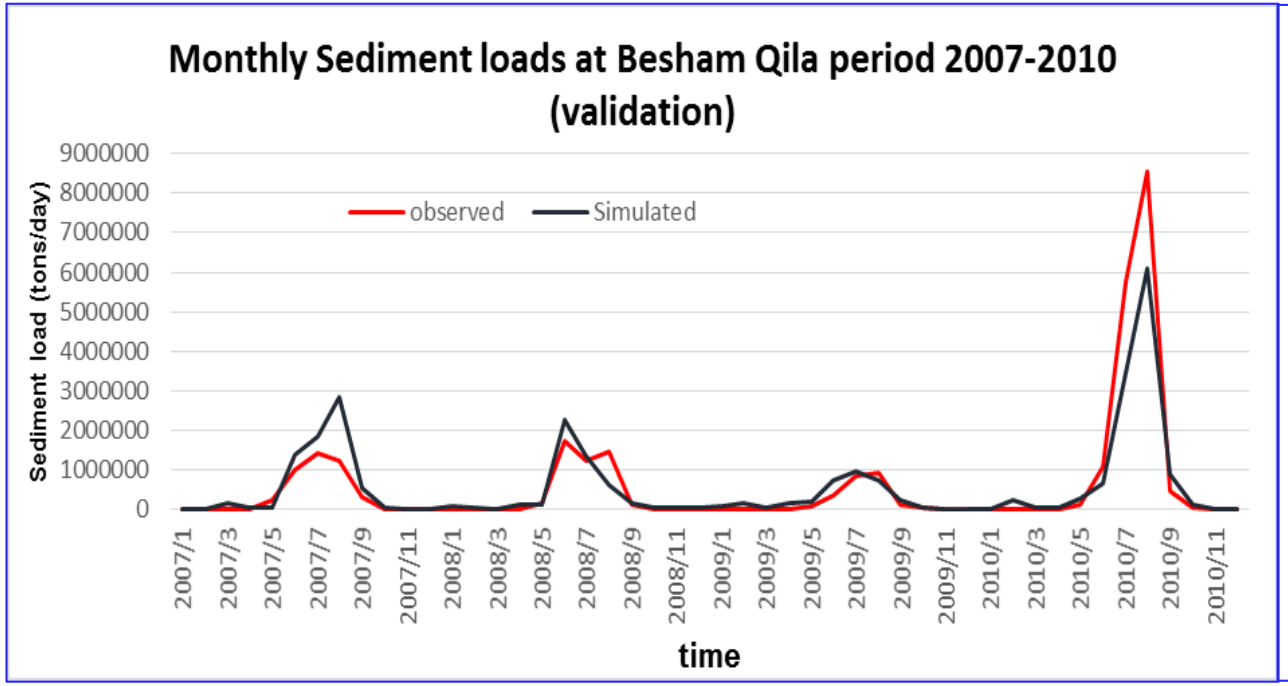
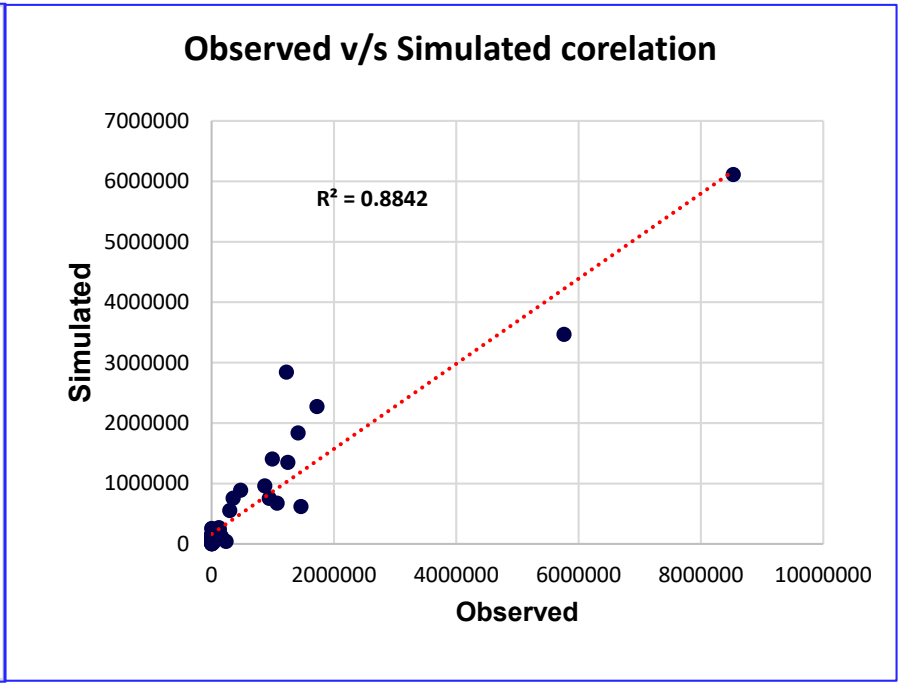
Validation for Sediment at Besham Qila

Observed
Average: 573121 tonnes

Simulated
566581 tonnes

NSE=0.85 PBIAS= + 1.14





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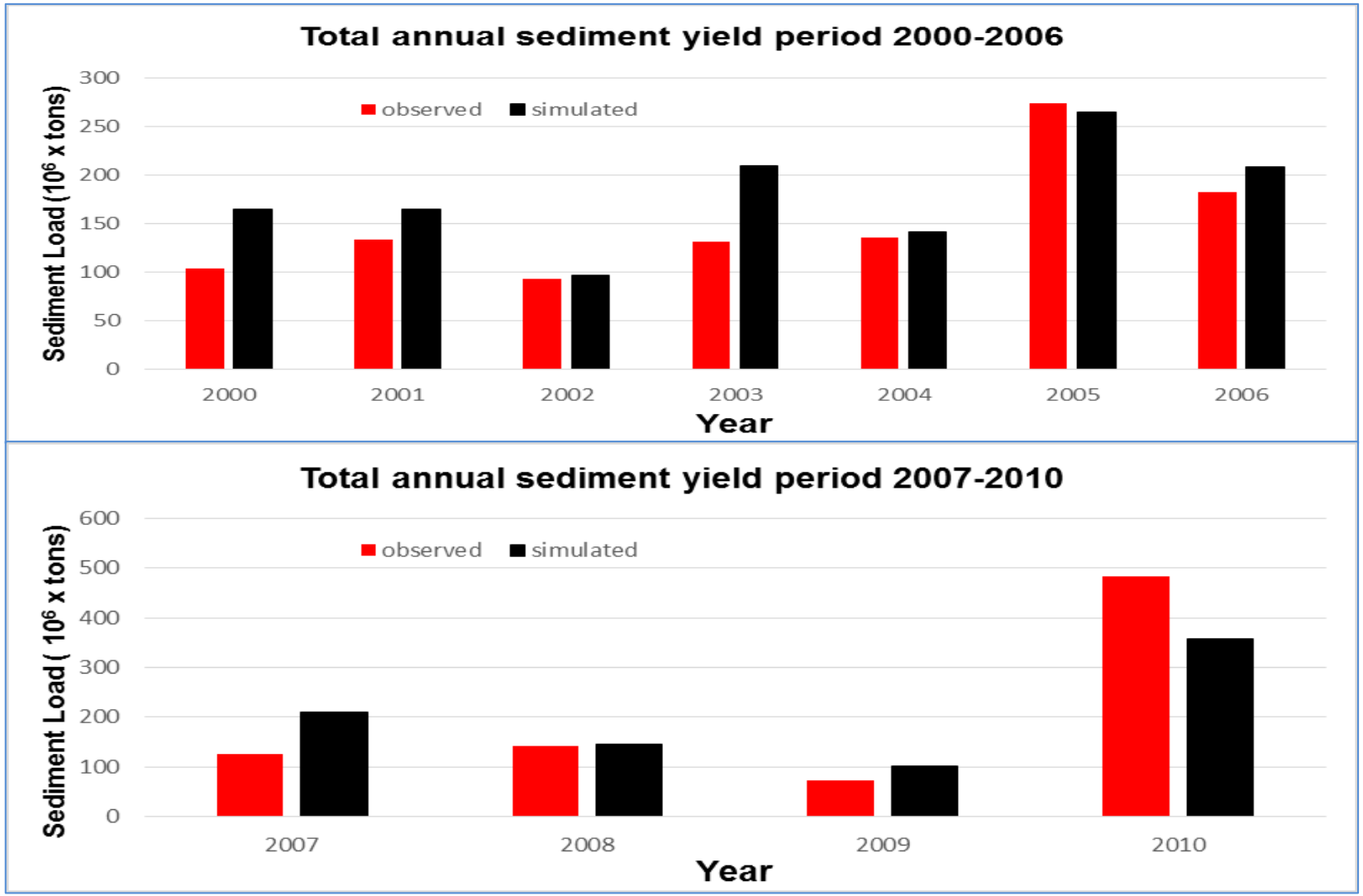
Total sediment yield comparison for Calibration & validation



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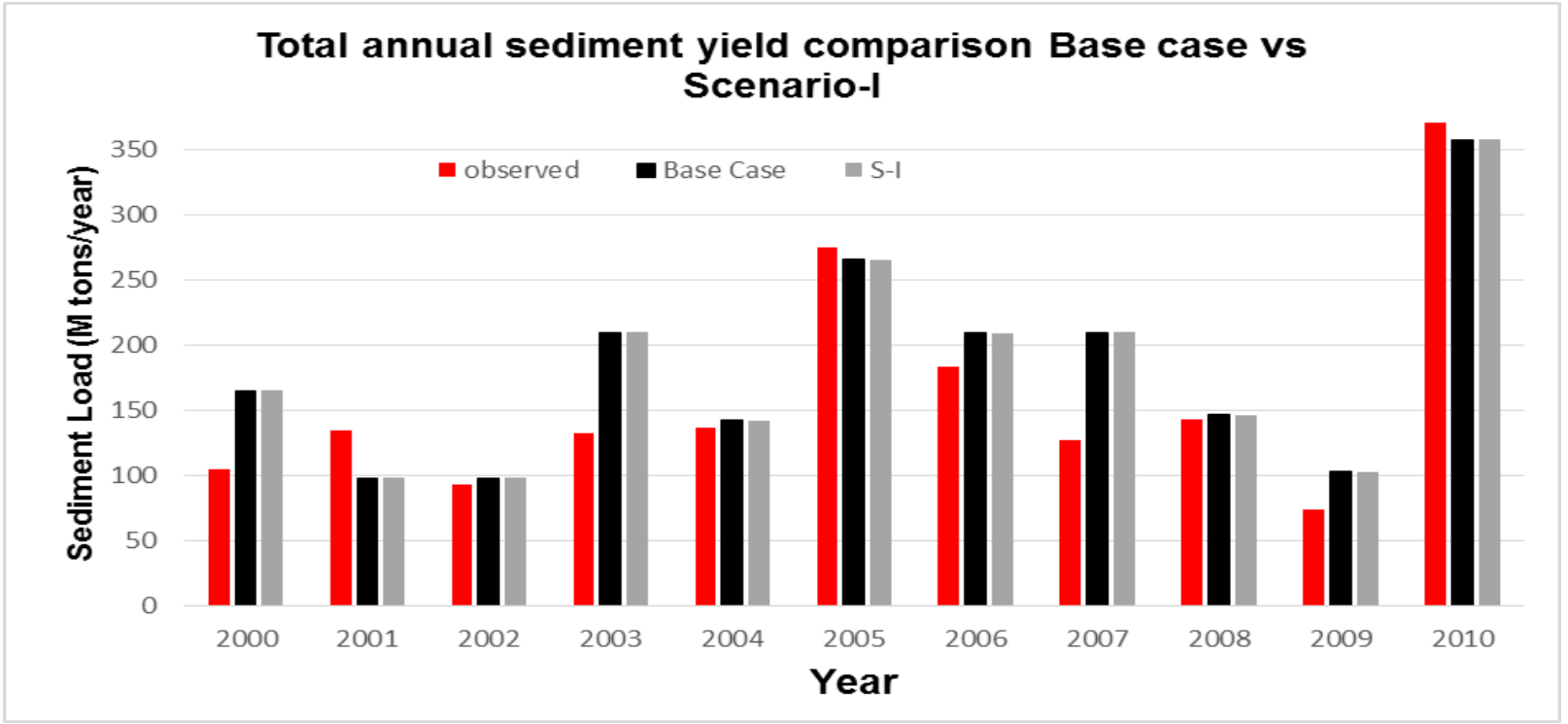
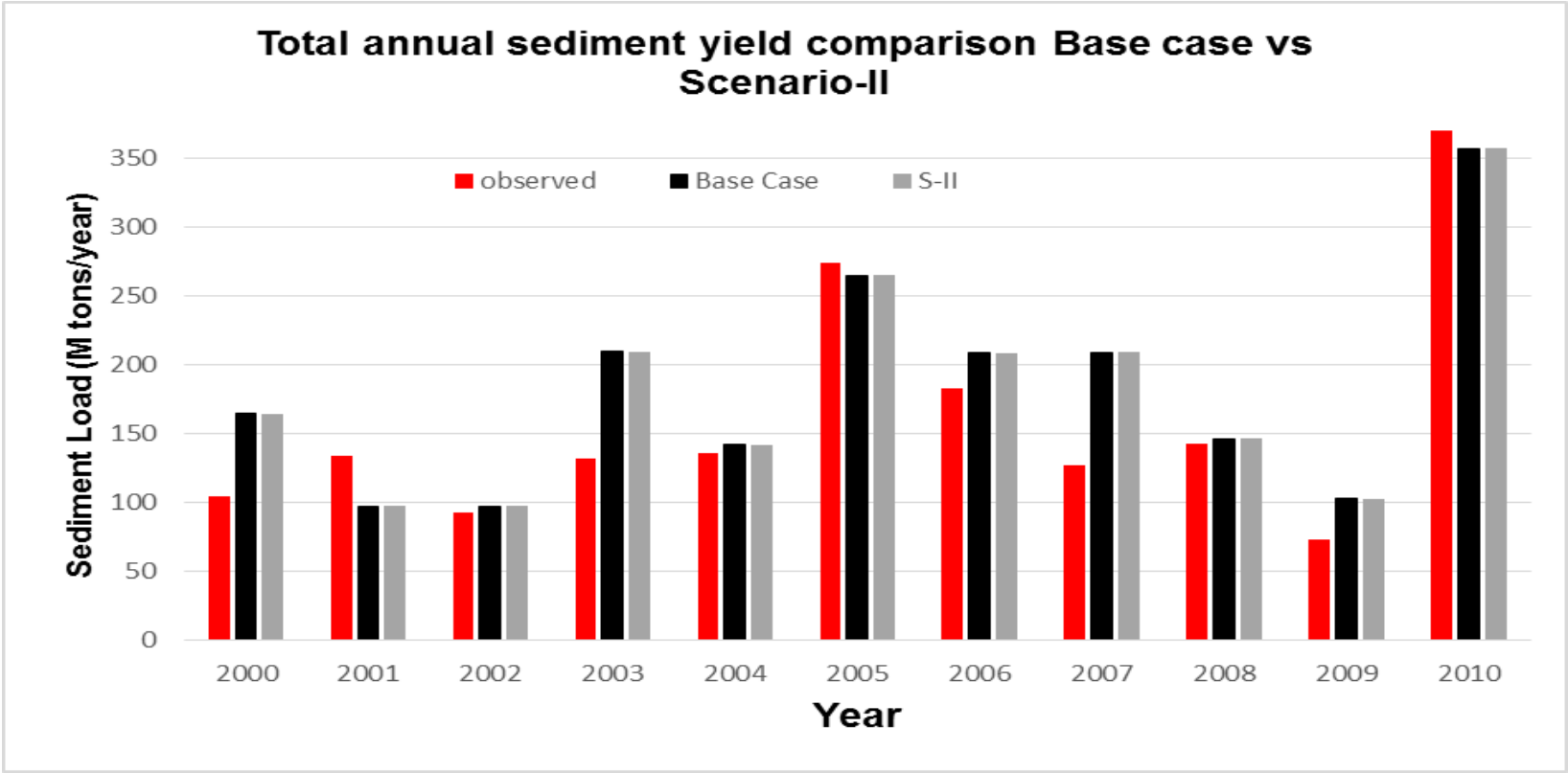
Land use Land cover change scenarios

i) **20% savanna (SAVD) replaced by forest (FRDA)**

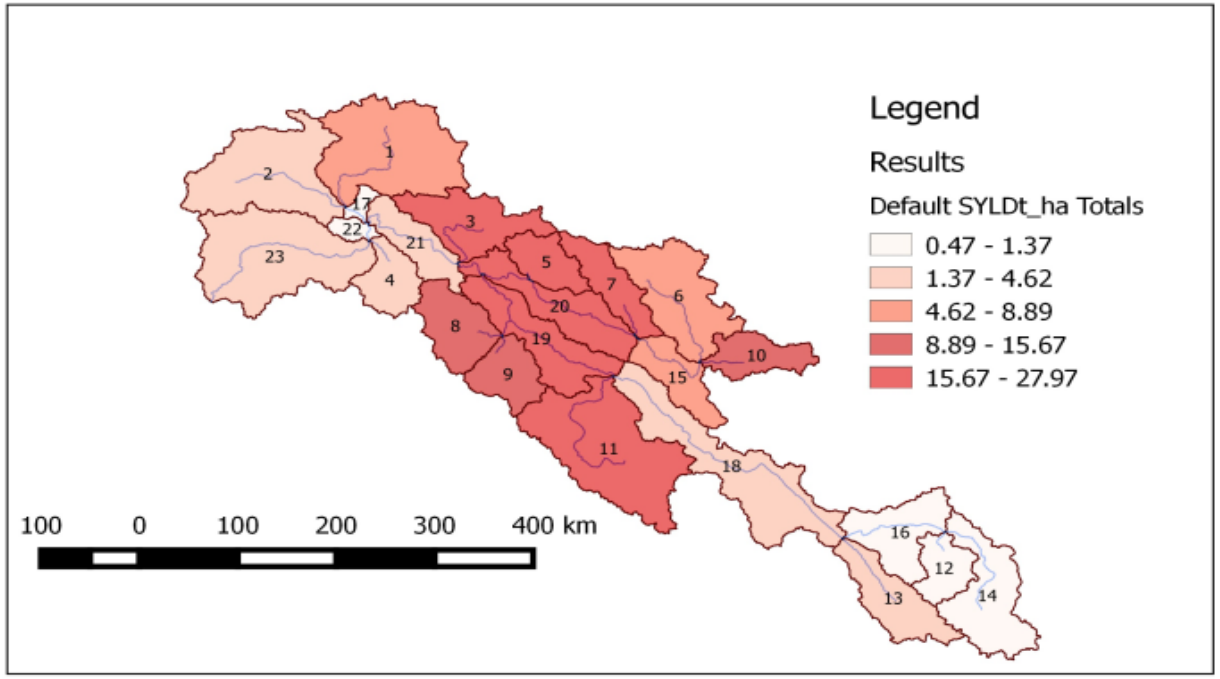


Land use Land cover change scenarios

ii) 40% savanna (SAVD) replaced by forest (FRDA)



Sediment yield map of UIB



Middle part of the catchment producing more sediment due to steep slopes with combination of lithosols.

Conclusion

- The results shows Billion Tree Tsunami project does not have significant impact on sediment yield of the basin even if 40% of the area under savana is replaced by forest.
- Morris (2014) based on observed data computed an average sediment yield of about 123 x 10^6 m^3 per year at Besham Qila. However, the calibrated/validated SWAT model estimate is about 96 x 10^6 m^3 per year.
- The most soil erosion prone sub basins as shown in sediment yield map, which will be useful for practicing engineers for watershed management. The middle part of the UIB emerges as the most erosion prone area.

Limitations of the study

- The meteorological stations are scarcely gauged within the administrative boundary of Pakistan and do not reflect the true representation of the catchment. Because of these limitations, complete meteorological data could not be obtained and it was not possible to develop the model on the basis of observed weather stations data.

- There were lack of sediment data availability at Kharmong and Partab Bridge gauging stations. Therefore, for sediment load calibration was not carried out but only was calibrated for runoff at these stations.

- Available observed meteorological data are found inconsistent due to large number of missing records which prohibited an acceptable degree of correlation analysis with satellite meteorological data.

- The results of model on north eastern catchments with area under glaciers were quite uncertain, due to SWAT's inability to adequately simulate glacier melt process.

Recommendations

- Future studies should also investigate the impact of other land use changes like urbanization, agriculture and deforestation. The future LULC change scenarios needs to be developed by considering socioeconomic trends in the catchment.
- Future studies should also look at erosions contribution due to landslides and earthquakes.
- The impact of proposed reservoirs upstream of Tarbela on sediment rates could be done using modelling approaches.
- The field level studies should be done on high sediment producing areas (middle part of the UIB) to formulate a sustainable sediment management.

Thanks!

Questions?