GEOMORPHOLOGY BASED HYDROLOGICAL INFORMATION SYSTEM FOR THE CATCHMENT OF RIVER KOSI SYSTEM LYING IN NEPAL

V.K. Dwivedi[1] and R. Berndtsson[2]

ABSTRACT

The Kosi river system lies in Nepal and northern India, where it has caused devastating floods throughout the years. The river is known for its dynamic flows and high sediment load, leading to one of the largest alluvial fans in the world as well as avulsed shifting. The monsoonal dynamics in the region causes high fluctuation in the river discharge, with almost annual flooding, often with destructive consequences. The Kosi river, which changes its course and washes away the homes and livelihoods of millions of people in Bihar, reinforces the need for effective water management on a priority basis. For effective water management, geomorphology based hydrological information system (GHIS) has been developed by considering a particular stream in the river system and rainfall-runoff models, based on geomorphology of the selected stream and hydro-meteorology data for the area covered by the stream, has been developed to enable real time availability of water in the river system on a local scale. Several GHIS developed for other streams would be integrated further to enable complete hydrological system for the river Kosi system to manage the water of river Kosi more efficiently.

INTRODUCTION

National Institute of Technology (NIT), Durgapur in cooperation with The Faculty of Engineering at Lund University are working to perform hydrological analysis and create Geomorphology based Hydrological Information System (GHIS) and develop Rainfall-runoff models based on geomorphological and hydro-meteorological data from the area to enable real time flood forecasting of the river and develop Decision Support System for Water Resources Management and Flood Mitigation in the catchment area of the river Kosi System.

OBJECTIVE

The objective of this study is to make a rainfall-runoff model for the upstream area of Kosi river system, which lies in Nepal. The modeling is simulated by two methods SCS-CN method and Artificial Neural Network (ANN) separately and results are compared at the end.

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1. Professor, National Inst. of Technology, Durgapur, India – 713209. Vkdwivedi10725@yahoo.co.in
2. Professor, Lund Univ., Lund, Sweden. Ronny.Berndtsson@tvrl.lth.se

2. THE KOSI RIVER SYSTEM

Table-1: Kosi River Short Facts

Kosi River Short Facts	
Catchment area:	69,300 km2
Catchment distribution:	Tibet; 42 %, Nepal: 45 % and India: 13 %
Length of river:	729 km (from its source to the Ganges)
Main tributaries:	Indravati, Sun Kosi, Tama Kosi, Likhu Kosi, Dudh Kosi, Arun Kosi and Tamar Kosi
Megafan:	Length: 180 km Width: 150 km Area: 10,351 km^2
Suspended load:	130 million m^3/year
Annual rainfall:	1,000-1,600 mm/year
Ave. annual discharge:	2,236 m^3/s
Ave. monsoon discharge:	5,156 m^3/s
Ave. non-monsoon discharge:	1,175 m^3/s

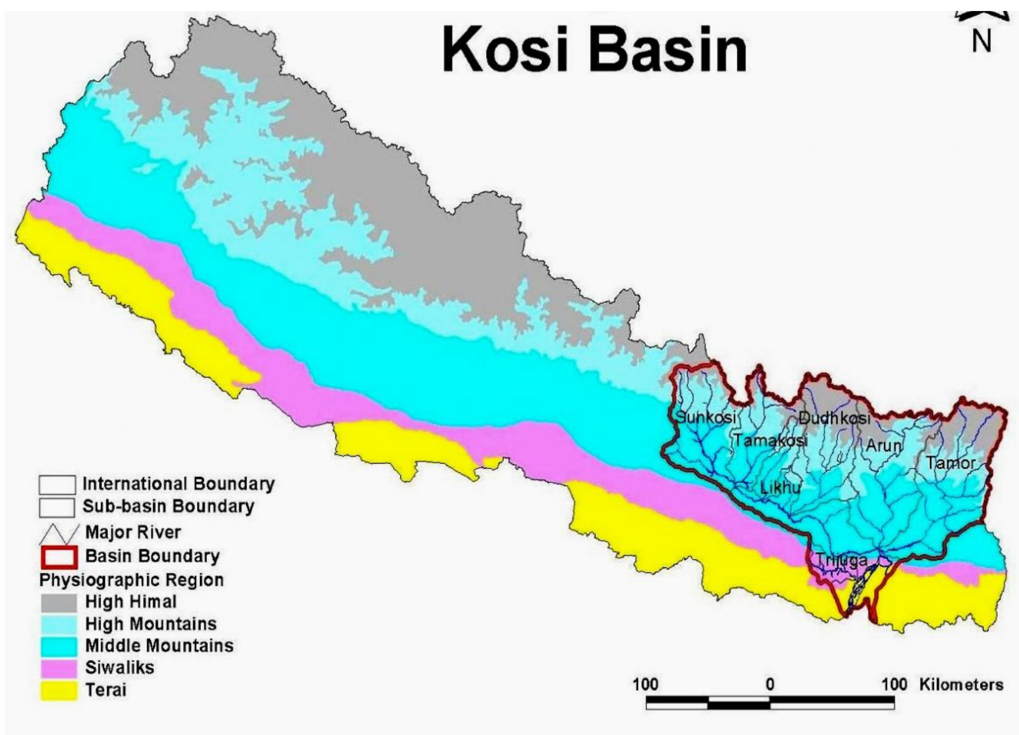

Figure 1: Kosi River basin in Nepal (Rapid hazard and risk assessment post-flood return analysis (2009) UNESCO on behalf of OCHA and UNCT, NEPAL)

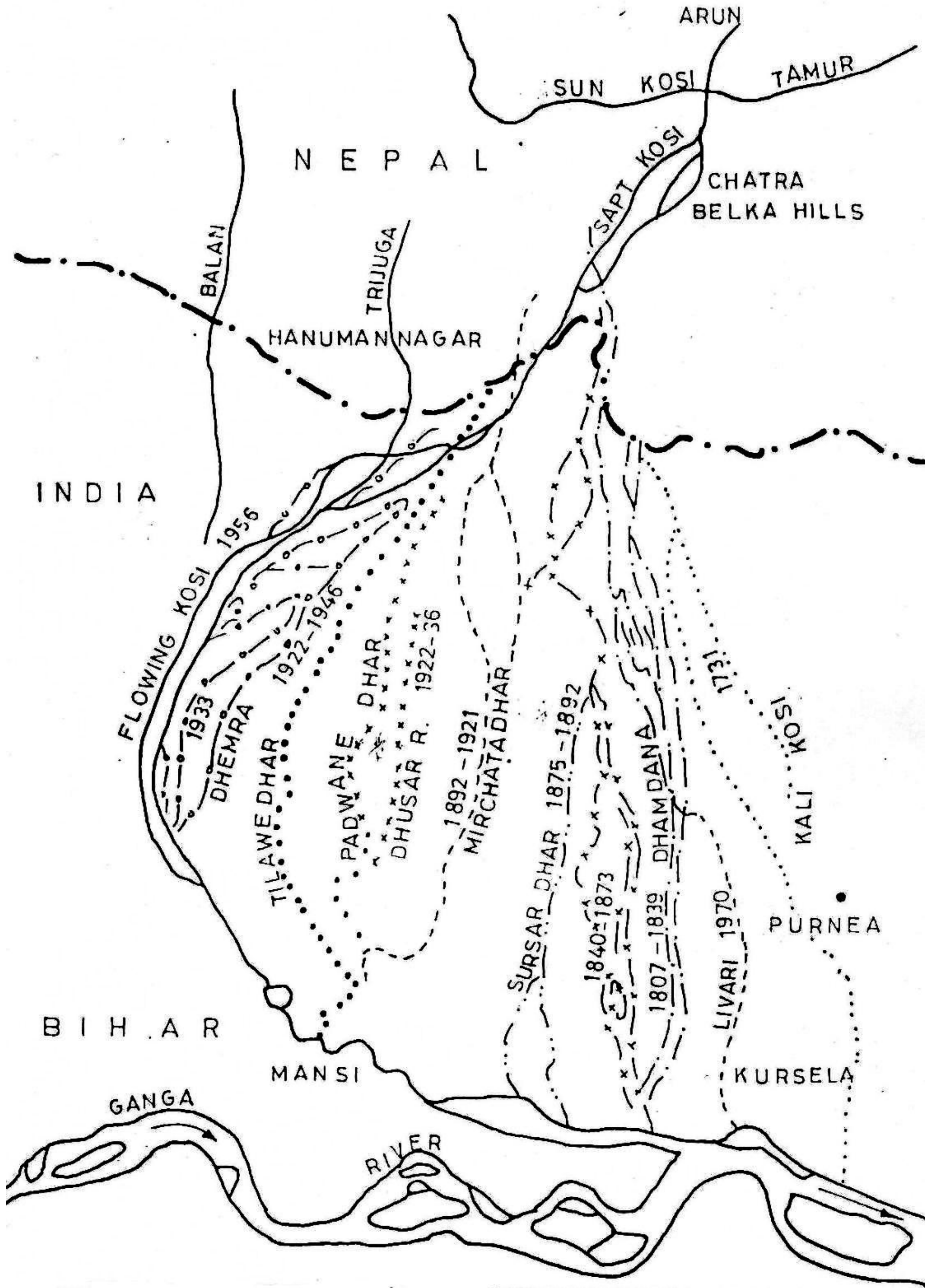

Figure 2: Kosi River shifting course and its paleochannels

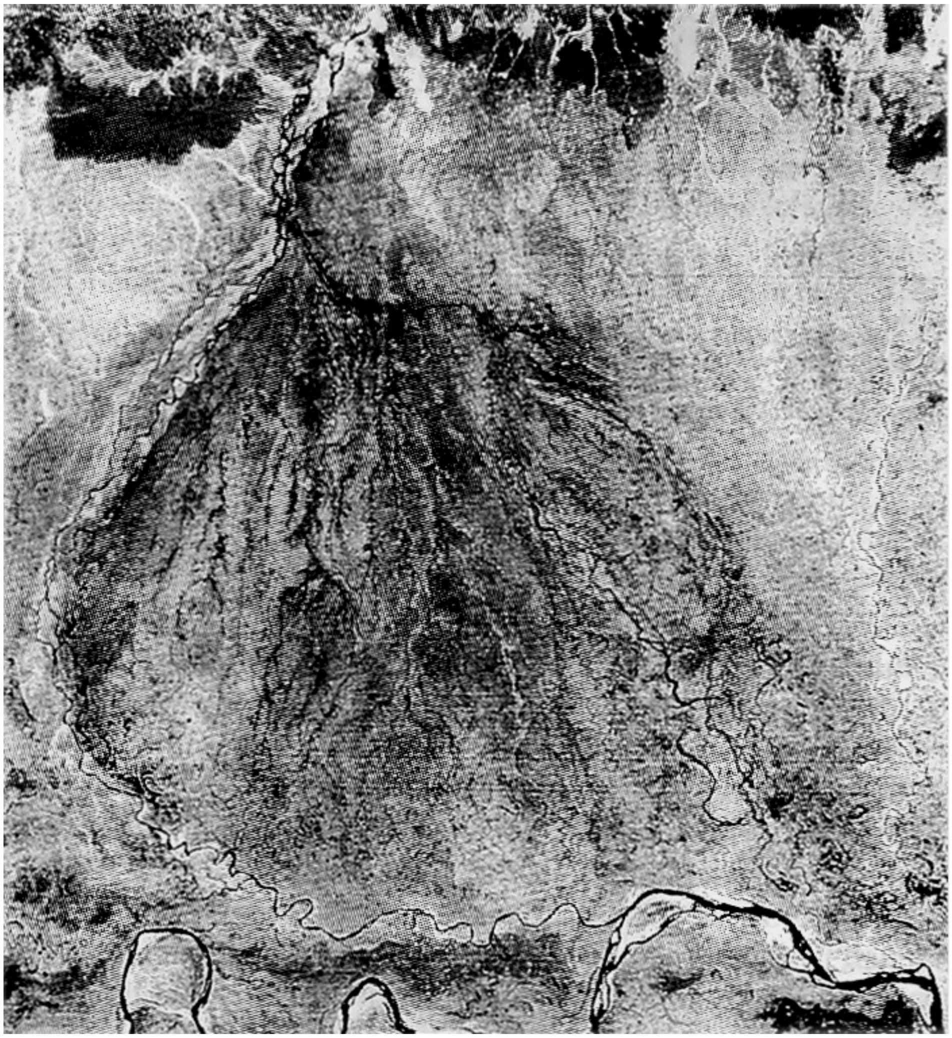

***Figure 3*:** Kosi River shifting course (Satellite Image)

*Figure 4***:** Kosi River basin in China, Nepal and India (Satellite Image) (Source: http://www.wwfnepal.org/our_solutions/conservation_nepal/maps_wwf_nepal/sacred_himalayan_landscape/koshi_river_basin/)

3. METHODOLOGY

The analysis is executed through: data quality check; trend analysis for individual parameters and rainfall-runoff correlations; flood frequency analysis. The first studies are conducted on a part of the catchment which is limited by six political districts in the southern part of Nepal: Saptari, Sunsari, Dhankuta, Udaypur, Khotang and Bhojpur, to study the behavior of the river as it exits Nepal and enters India. Later the area is limited further to a sub-basin of the catchment which is determined from the topography of the area.

a. DATA

Precipitation and discharge data is procured from the Department of Hydrology and Meteorology in Kathmandu, Nepal. The precipitation data covers daily rainfall from 1996 to 2008 for 16 stations within the selected districts, with varying quality and temporal coverage depending on stations. The discharge is measured at 12 discharge stations with a temporal coverage from 1964 to 2006, depending on stations.

***Table-2*:** Meteorological stations used in the analysis with location and elevation.

Meteorological Stations				
Index No	**District**	**Latitude (deg min)**	**Longitude (deg min)**	**Elevation of station (m)**
1212	Saptari	26 44	86 56	100
1223	Saptari	26 33	86 45	91
1226	Saptari	26 36	86 54	85
1311	Sunsari	26 49	87 17	444
1316	Sunsari	26 49	87 10	183
1320	Sunsari	26 42	87 16	200
1304	Dhankuta	27 03	87 17	1680
1305	Dhankuta	27 08	87 17	410
1306	Dhankuta	27 02	87 14	1317
1308	Dhankuta	26 56	87 20	365
1309	Dhankuta	26 56	87 09	143
1322	Dhankuta	26 58	87 10	158
1213	Udaypur	26 56	86 31	1175
1227	Udaypur	26 47	86 43	152
1211	Khotang	27 02	86 50	1295
1325	Bhojpur	27 22	87 09	1190

***Table-3*: Discharge stations used in the analysis with location, elevation, quality and drainage basin size defined.**

Discharge Stations						
Index No	**River**	**Lat (deg min sec)**	**Long (deg min sec)**	**Elevation of station (m)**	**Quality**	**Basin Size (km^2)**
602	Sabhayakhola	27 18 20	87 13 15	305	Fair	375
602.5	Hinwakhola	27 17 45	87 13 30	300	Poor	110
604.5	Arun River	27 20 00	87 11 30	414	Good	28200
606	Arun River	26 55 30	87 09 30	152	Poor	30380
660	Likhu Khola	27 20 10	86 13 10	543	Good	823
670	Dush Kosi	27 16 00	86 39 50	460	Good	4100
652	Sun Kosi	27 20 00	86 00 00	455	Good	10000
680	Sun Kosi	26 52 30	86 49 20	200	Good	17600
681	Sun Kosi	26 55 15	87 08 45	150	Fair	18700
684	Tamur River	27 09 30	87 42 45	533	Good	4050
690	Tamur River	26 55 50	87 19 45	276	Fair	5640
695	Sapt Kosi	26 52 00	87 09 30	140	Fair	54100

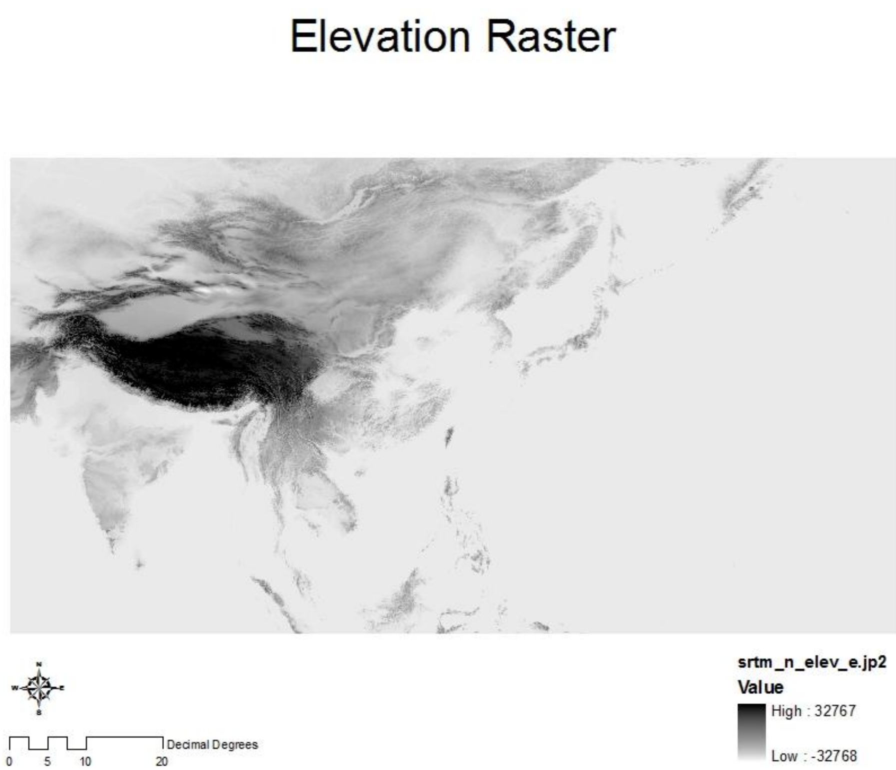

***Figure-5*: Digital Elevation Model (DEM) from ESRI**

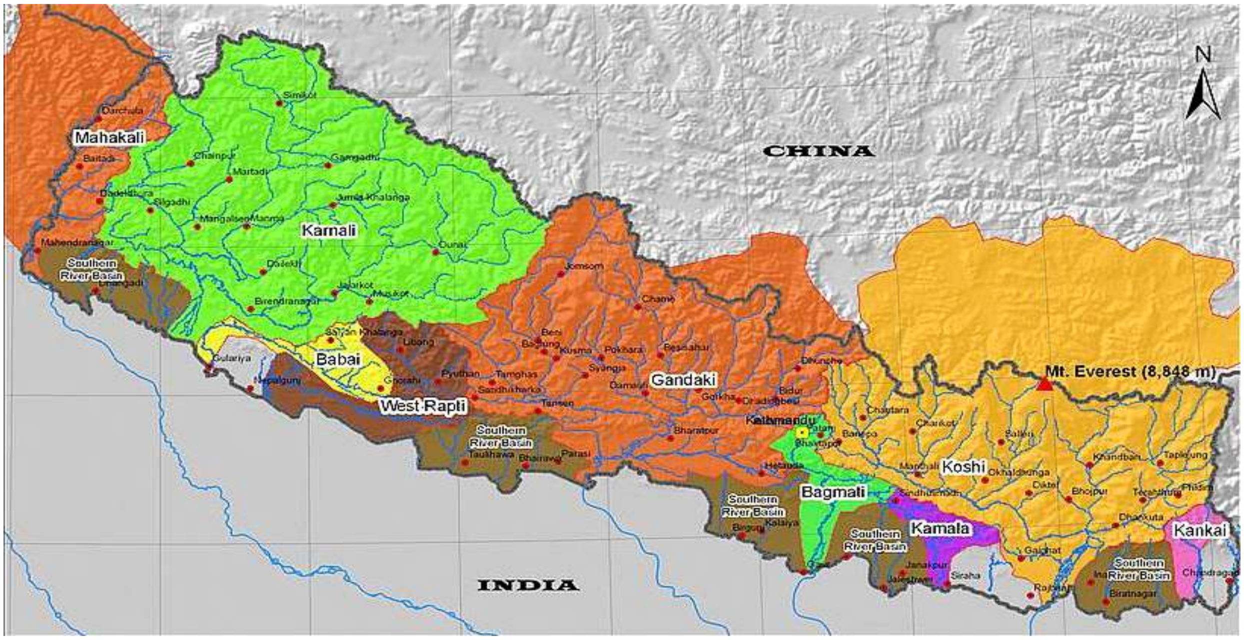

***Figure-6*:** Nepal map with rivers and streams from WWF-Nepal

(Source:http://www.wwfnepal.org/our_solutions/conservation_nepal/maps_wwf_nepal/sacred_himalayan_landscape/koshi_river_basin/)

4. RESULTS

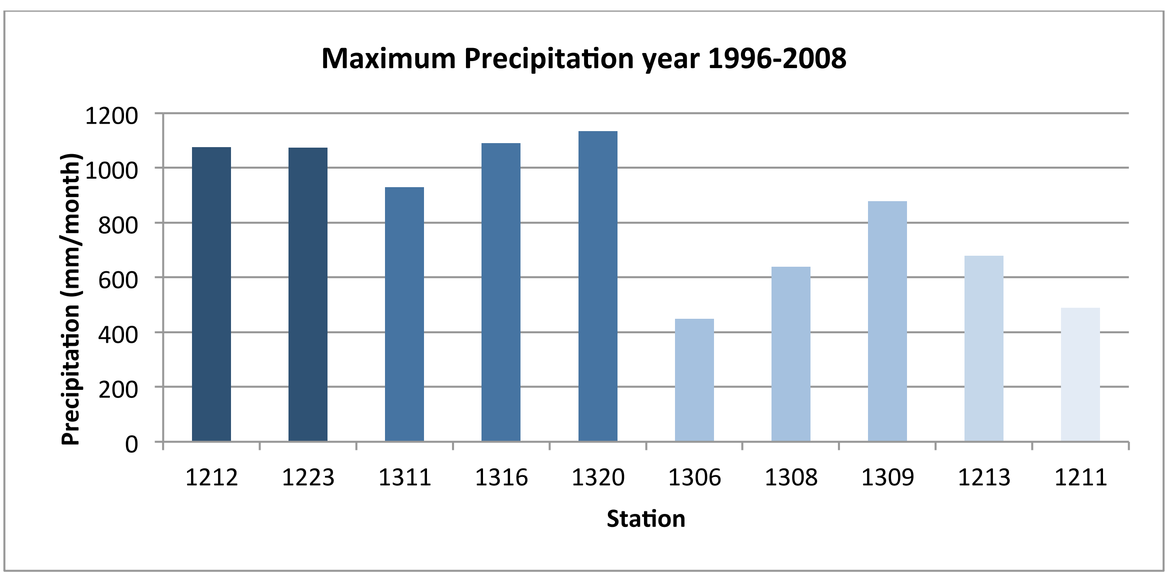

***Figure-7*:** Maximum total monthly precipitation in the time period of 1996-2008

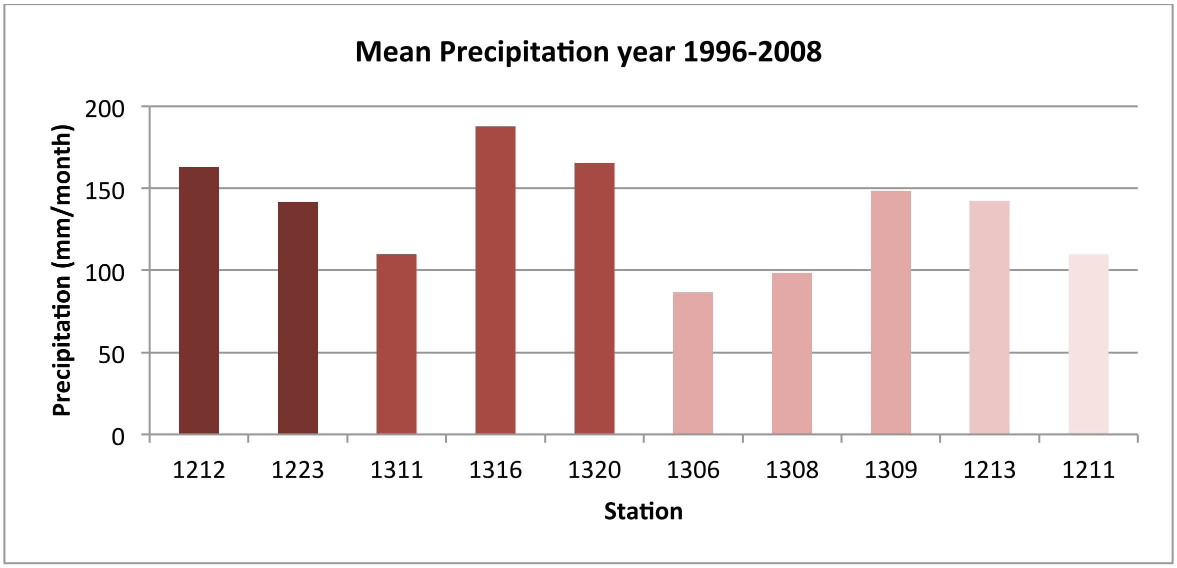

Figure-8: Mean total monthly precipitations from the time period of 1996-2008

DOUBLE MASS CURVE

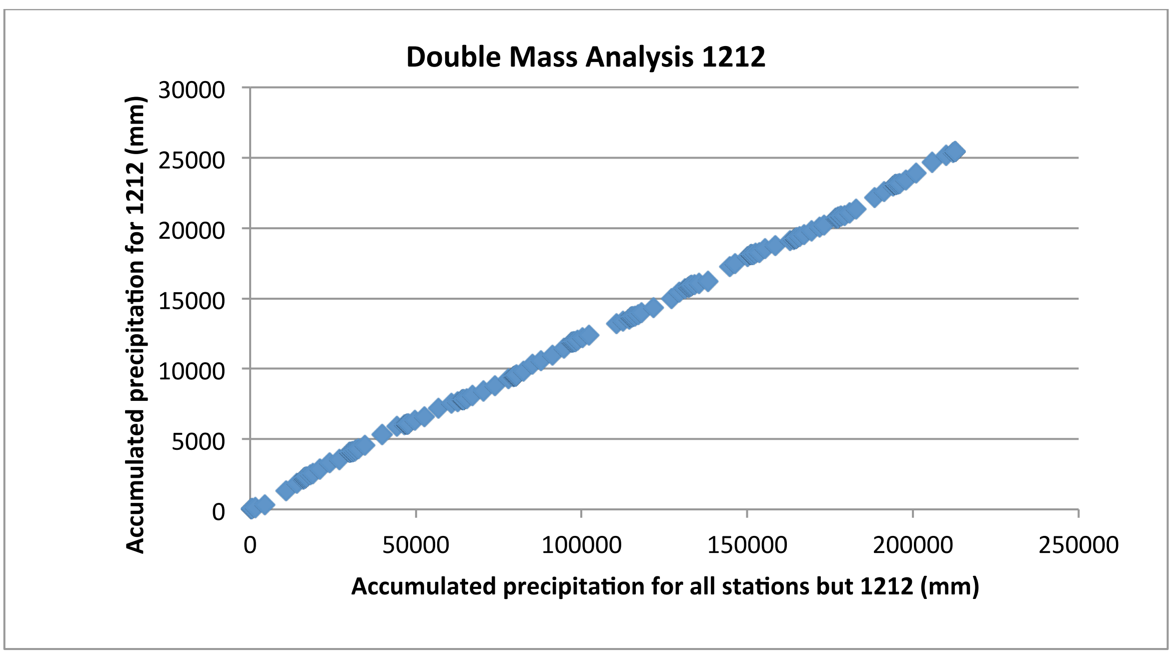

Figure-9: Double mass analysis where the linearity is good, station 1212

TRENDS

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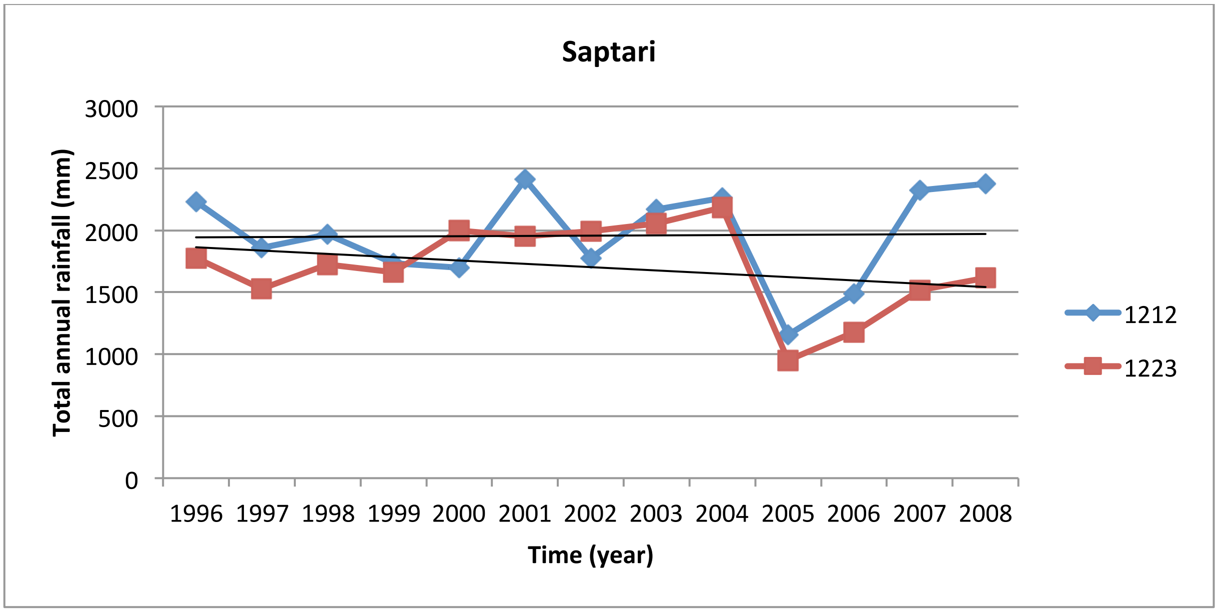


Figure-10: Annual total rainfall at the stations in the Saptari district, with trend lines.

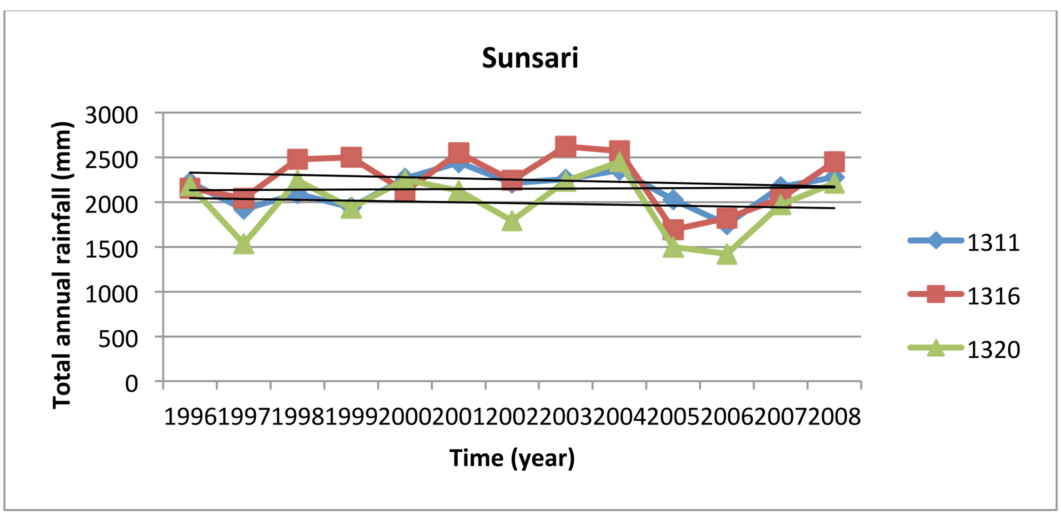


Figure-11: Annual total rainfall at the stations in the Sunsari district, with trend lines.

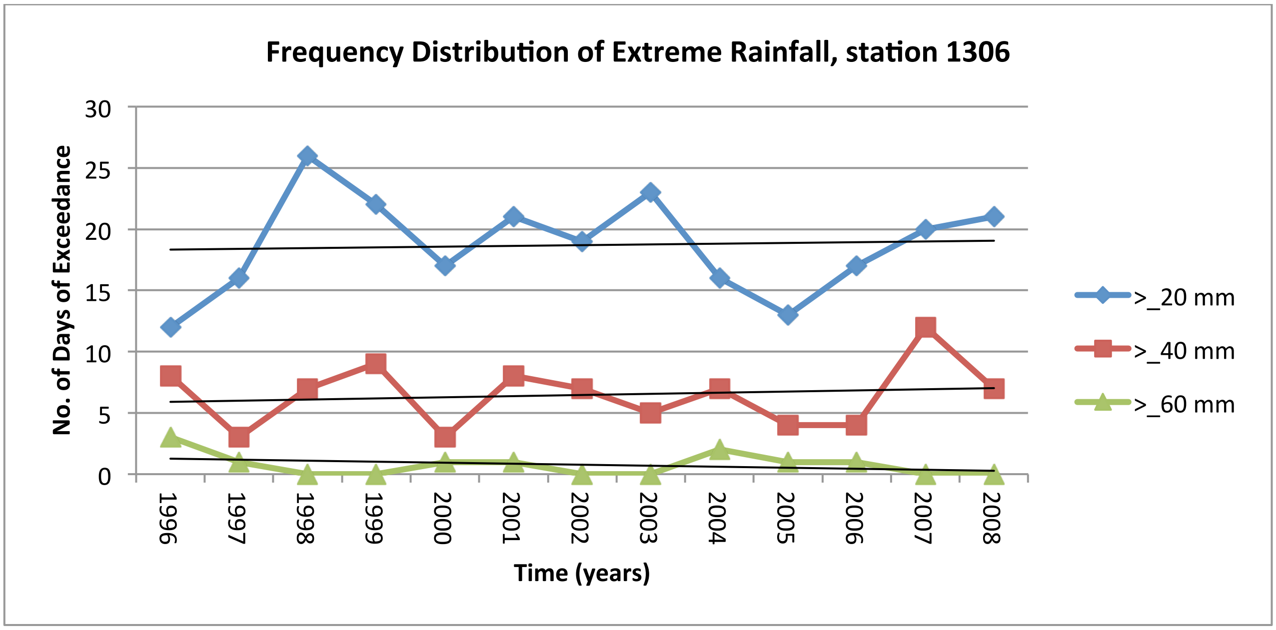


***Figure-12*:** Frequency distribution of extreme rainfalls at station 1306, Dhankuta

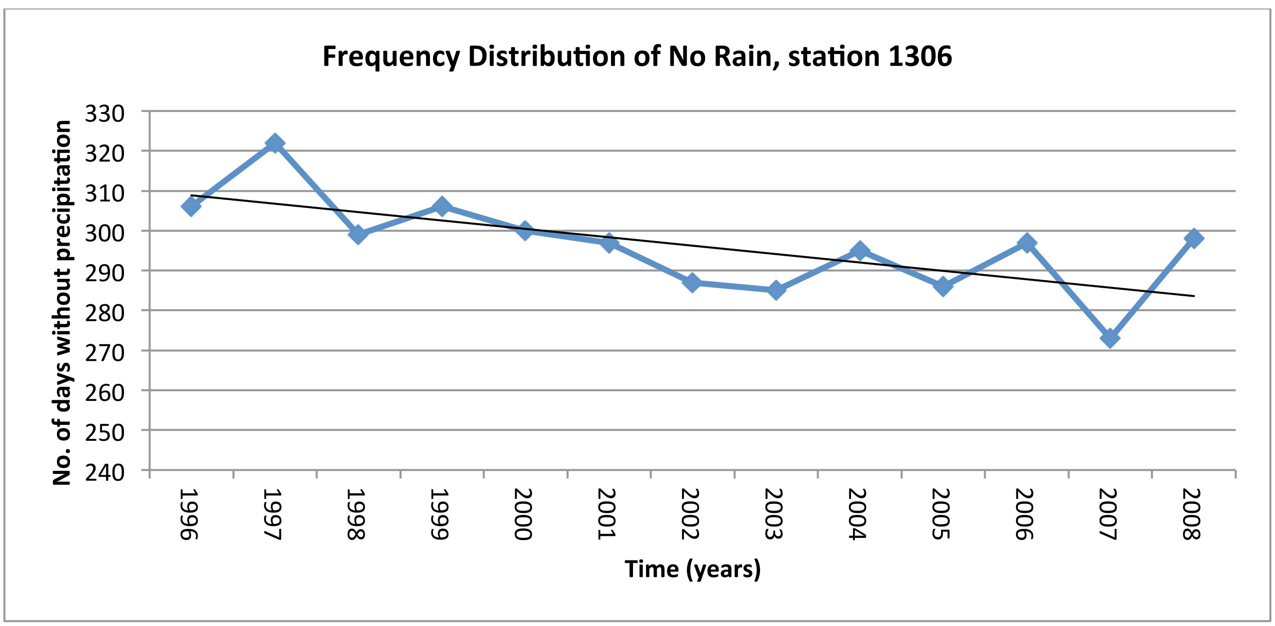


***Figure-13*:** Frequency distribution of no rainfall days at station 1306, Dhankuta

DISCHARGE

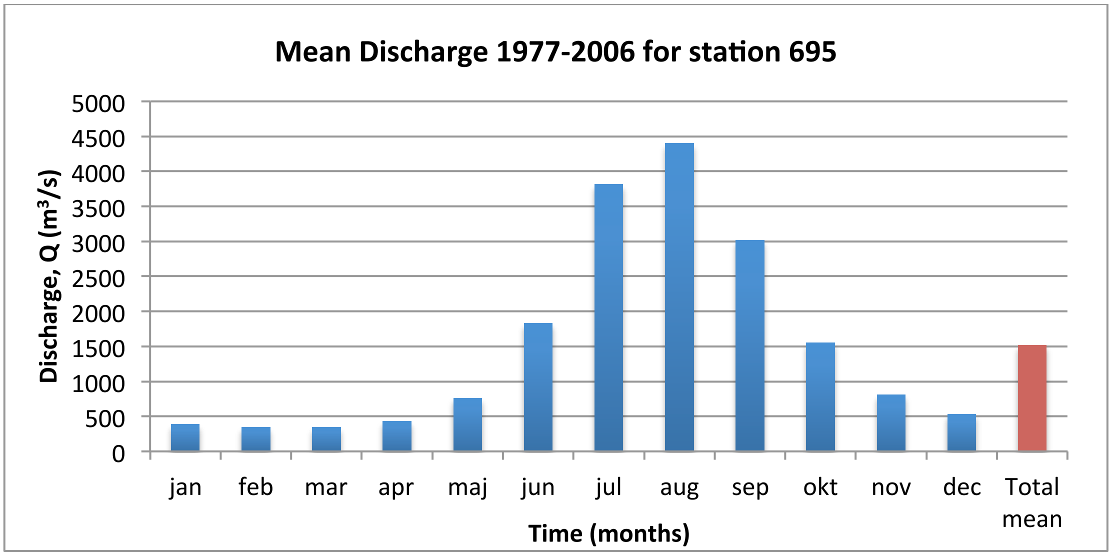
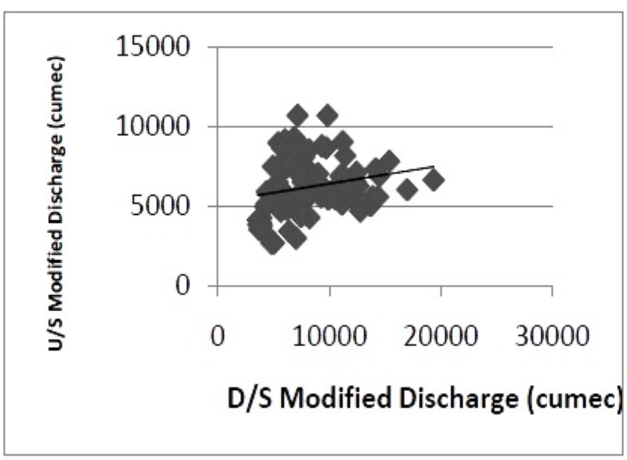


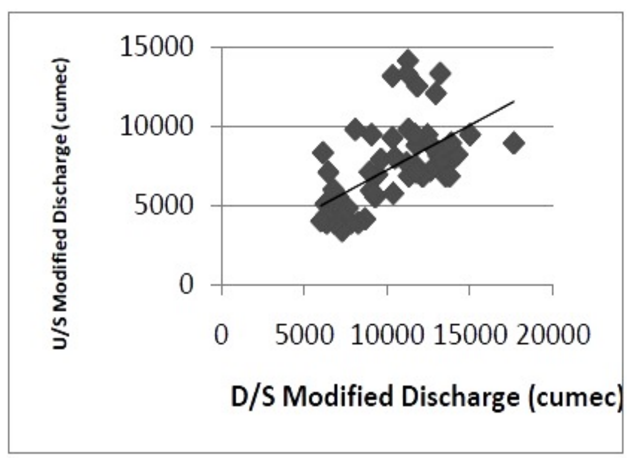
Figure-14: Mean monthly discharge and total mean discharge for the whole data set for station 695 between 1977-2006. Highest average flow is observed in August (4399 m^3/s) and the lowest in February (343 m^3/s).

UPSTREAM AND DOWNSTREAM DISCHARGE RELATION

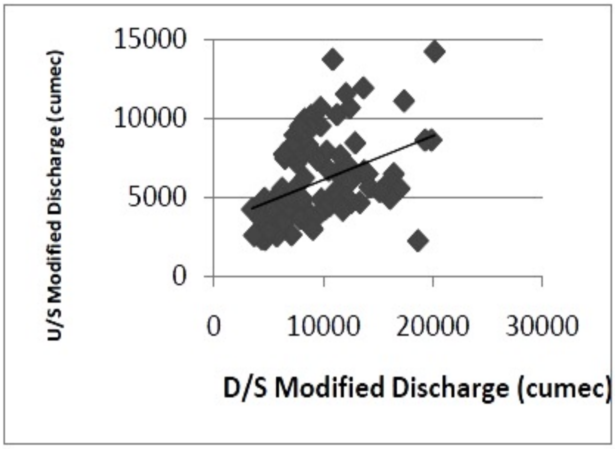
The two discharge stations considered, Barah kshetra, Nepal and Bhimnagar, India, of which Barah kshetra lies in the mountain regions and makes it upstream of the river Kosi whereas Bhimnagar lies in relatively Planner area and is far downstream very close to the India-Nepal Border. So relationships have been plotted between modified discharge of upstream and downstream.



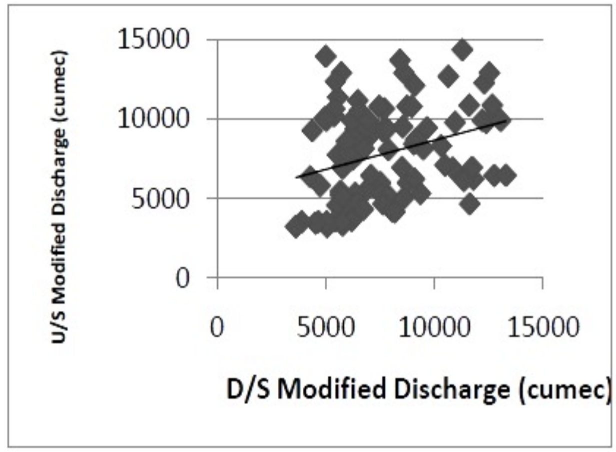
(a)



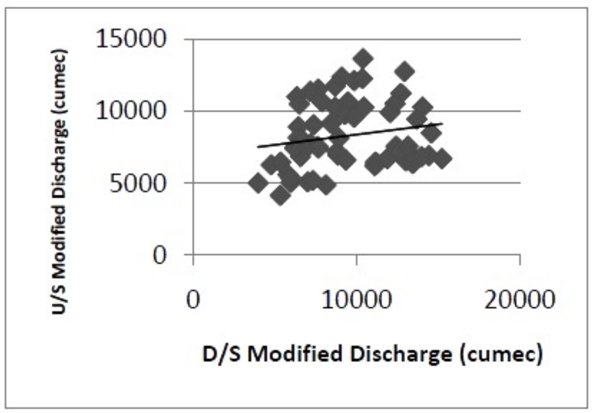
(b)



(c)



(d)



(e)

***Figure-15*:** Upstream v/s Downstream Modified discharge relation of year, (a) 2005, (b) 2006, (c)2007, (d) 2008 and (e) 2009.

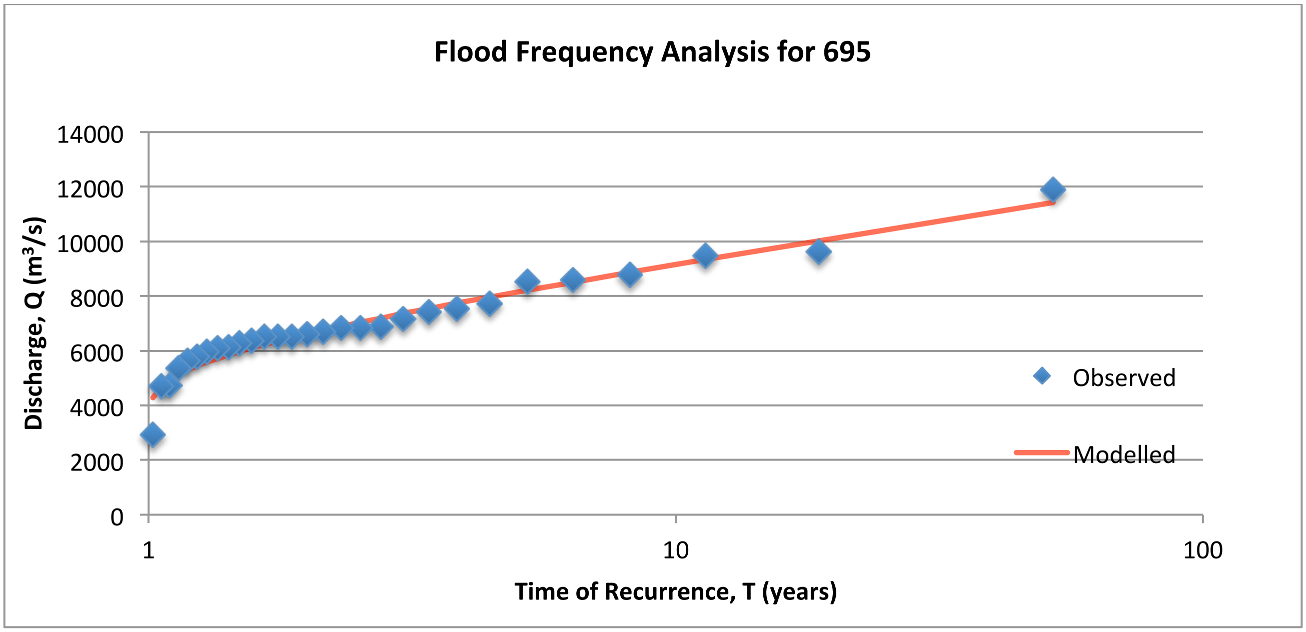
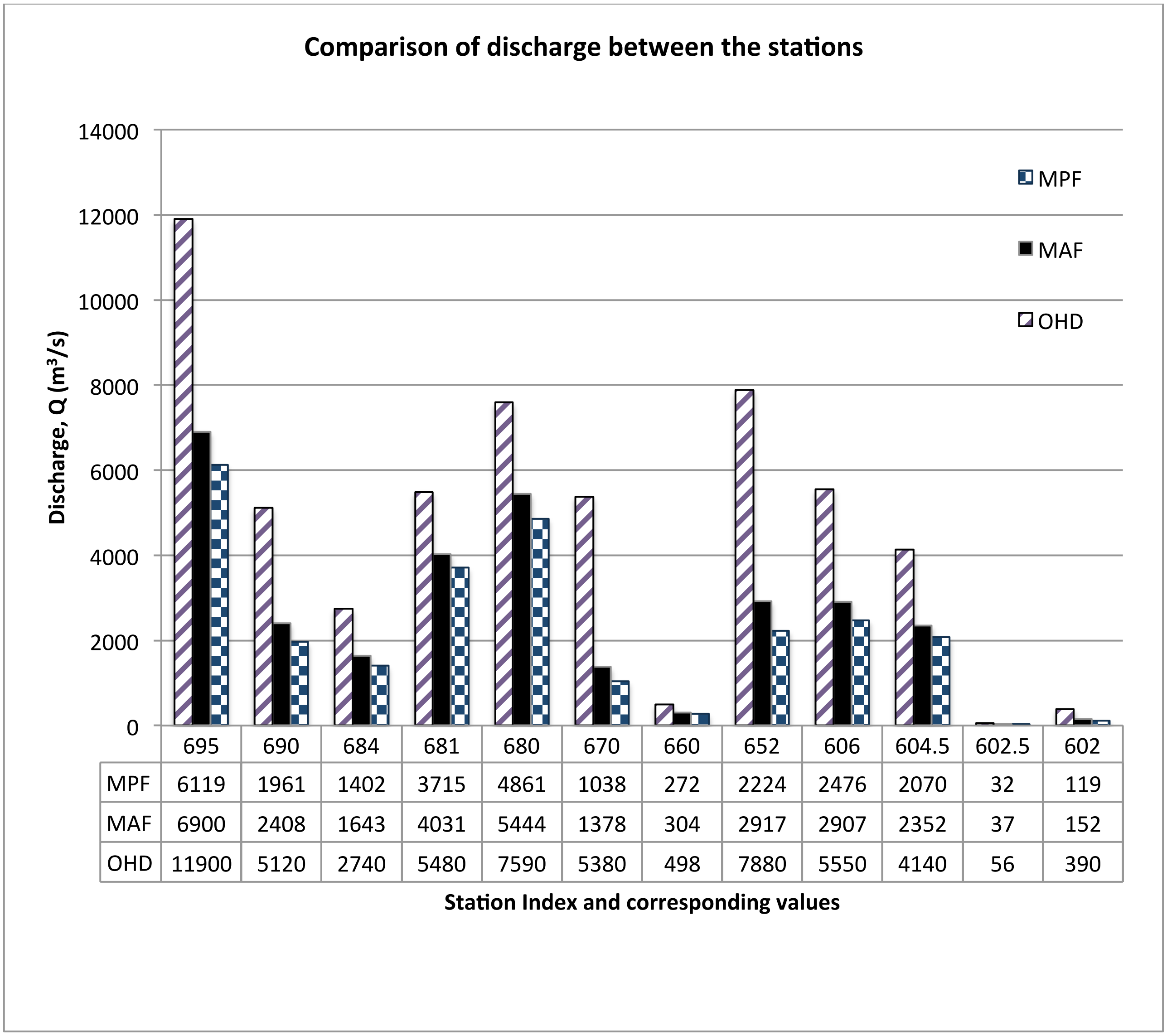
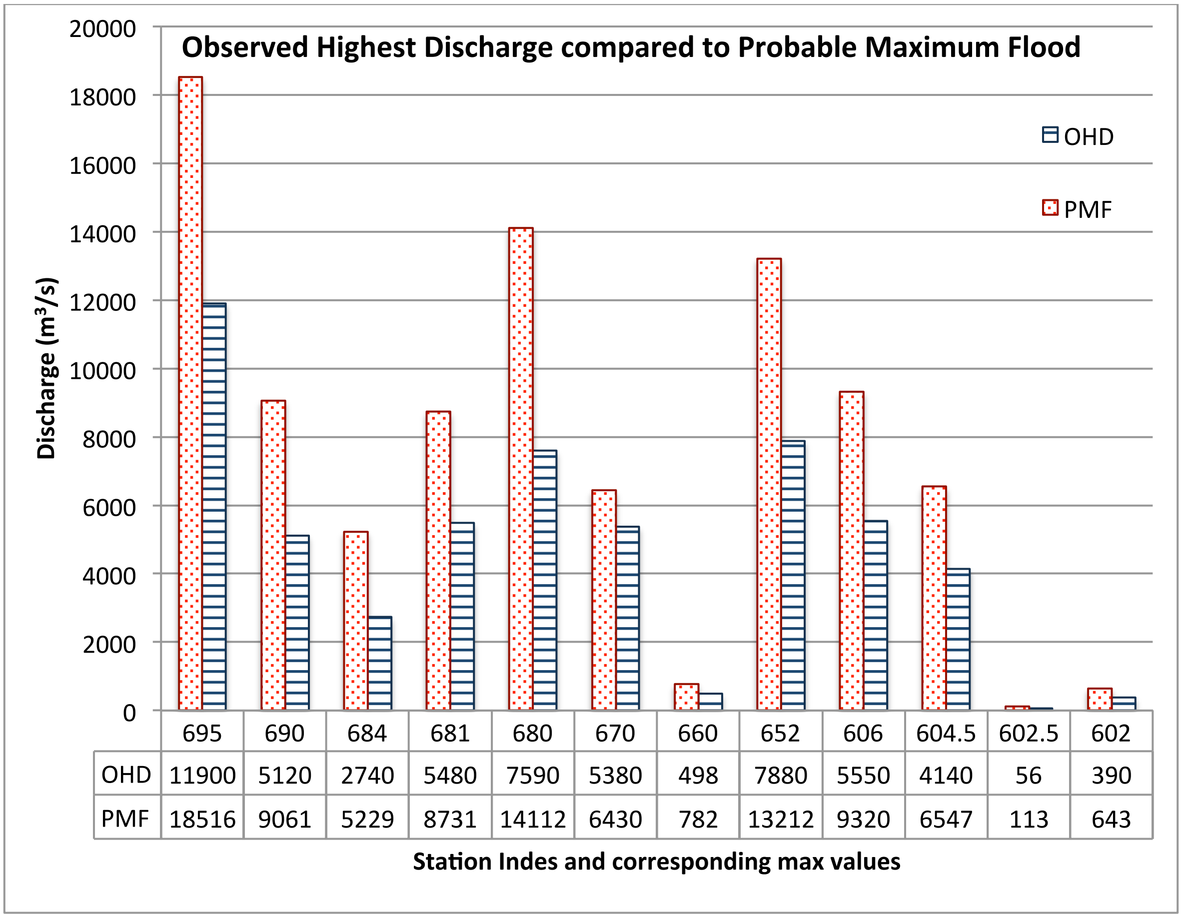


Figure-16: Flood frequency analysis for 695 with the fitted model to the recorded data.



	695	690	684	681	680	670	660	652	606	604.5	602.5	602
MPF	6119	1961	1402	3715	4861	1038	272	2224	2476	2070	32	119
MAF	6900	2408	1643	4031	5444	1378	304	2917	2907	2352	37	152
OHD	11900	5120	2740	5480	7590	5380	498	7880	5550	4140	56	390

***Figure-17(a)*:** Comparison of Most Probable Flood (T = 1.58 years), Mean Annual Flood (T=2.33 years) and Observed Highest Discharge for the discharge stations within the study area.



	695	690	684	681	680	670	660	652	606	604.5	602.5	602
OHD	11900	5120	2740	5480	7590	5380	498	7880	5550	4140	56	390
PMF	18516	9061	5229	8731	14112	6430	782	13212	9320	6547	113	643

***Figure-17(b)*:** Comparison of Observed Highest Discharge with Probable Maximum Flood (T = 10,000 years) for the discharge stations within the study area.

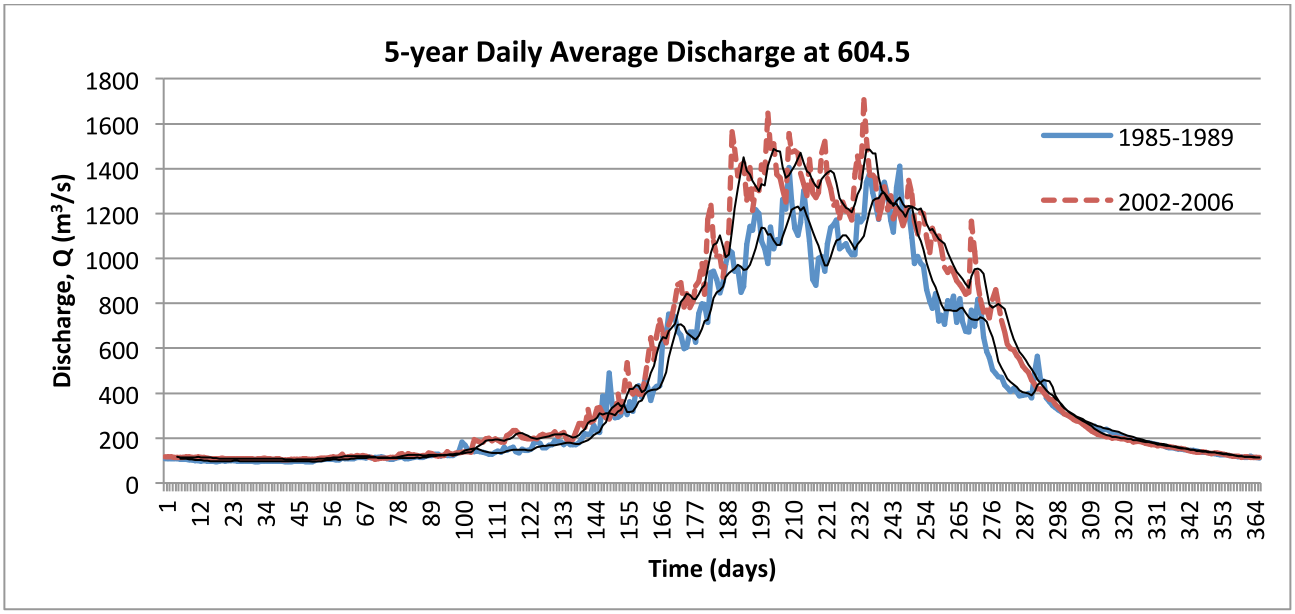


***Figure-18*:** 5-Year daily average discharge for two time spans: 1985-1989 and 2002-2006 at station 604.5. Discharge during the monsoon period was greater between the years 2002-2006 compared to 1985-1989.

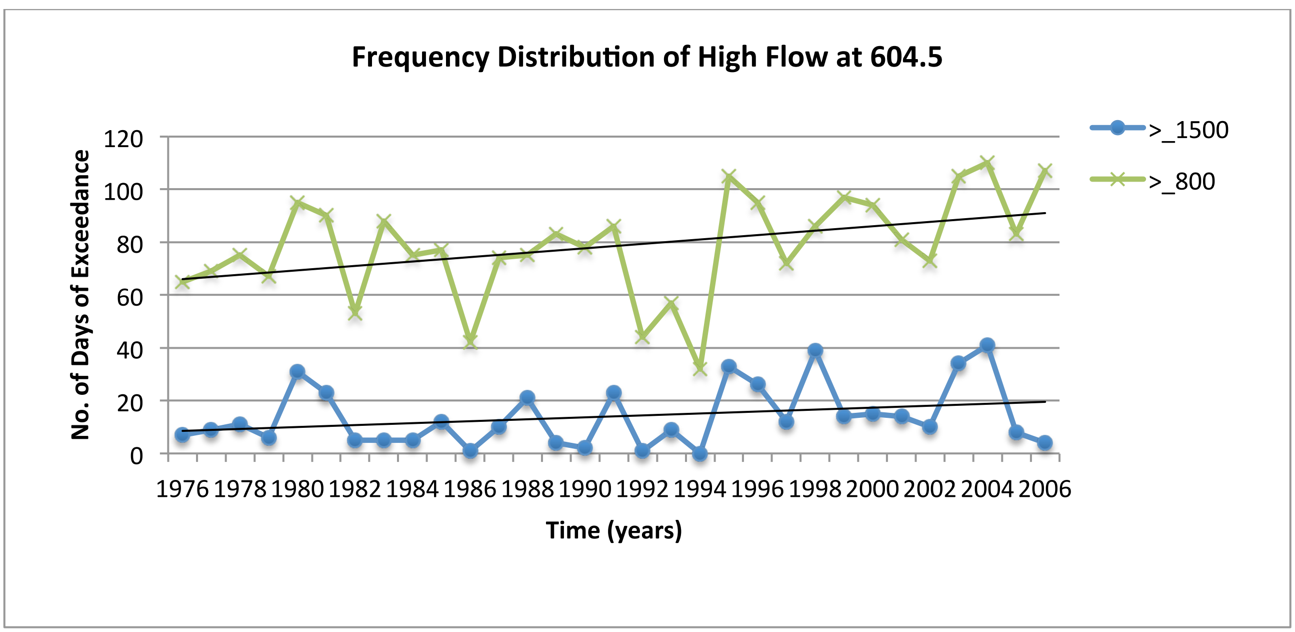


Figure-19: Frequency distribution of High Flow at 604.5 between 1976-2006 for flows equal to or exceeding 800 and 1500 m^3/s.

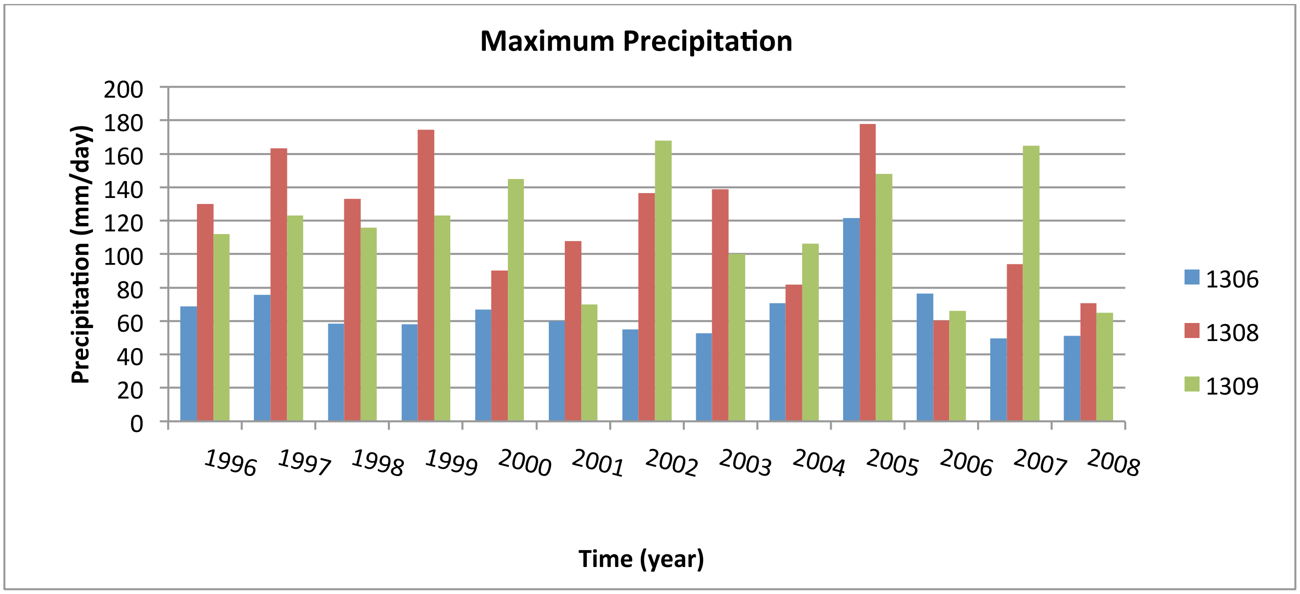


Figure-20: Maximum daily precipitation for each year at the three meteorological stations

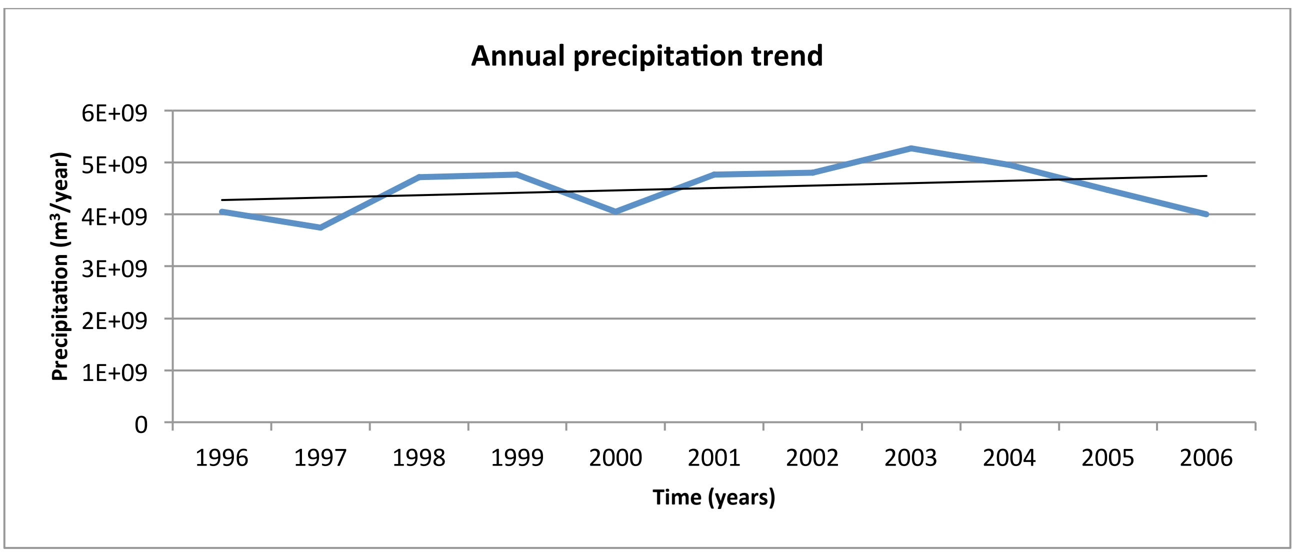


Figure-21: Calculated annual precipitation in sub-basin.

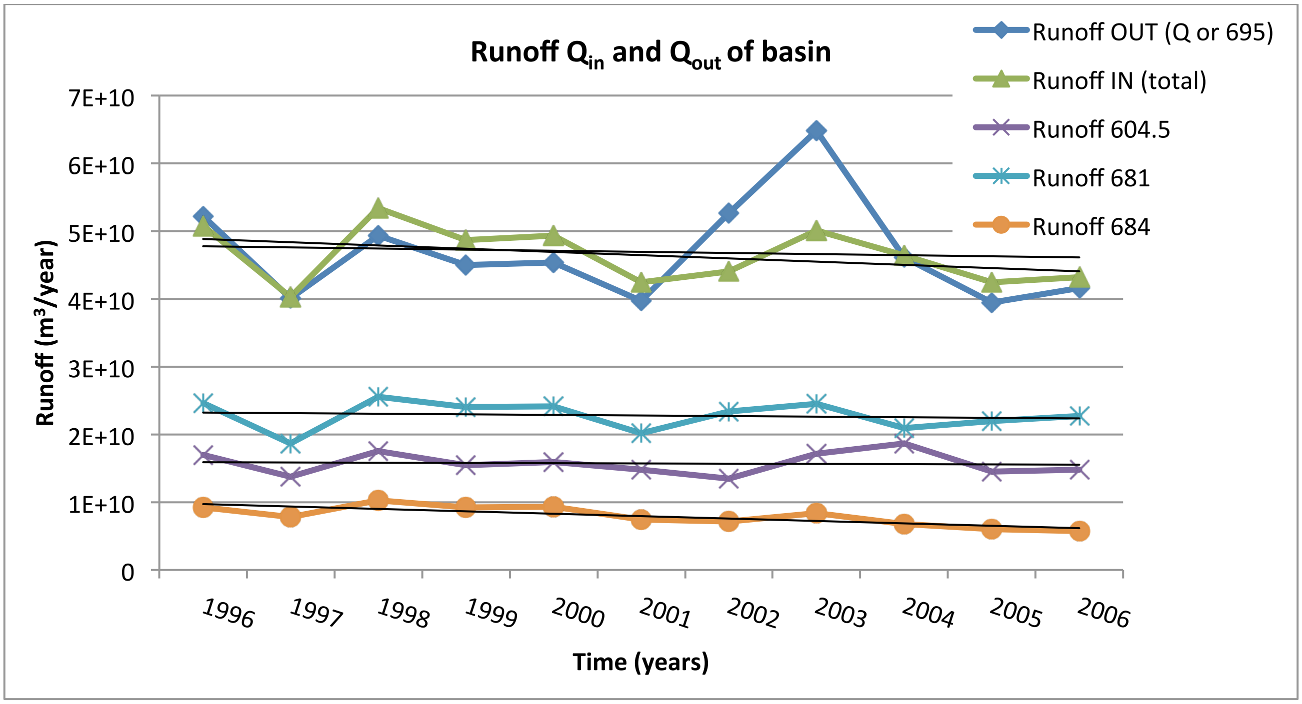


Figure-22: Calculated annual runoff into and out of the sub-basin.

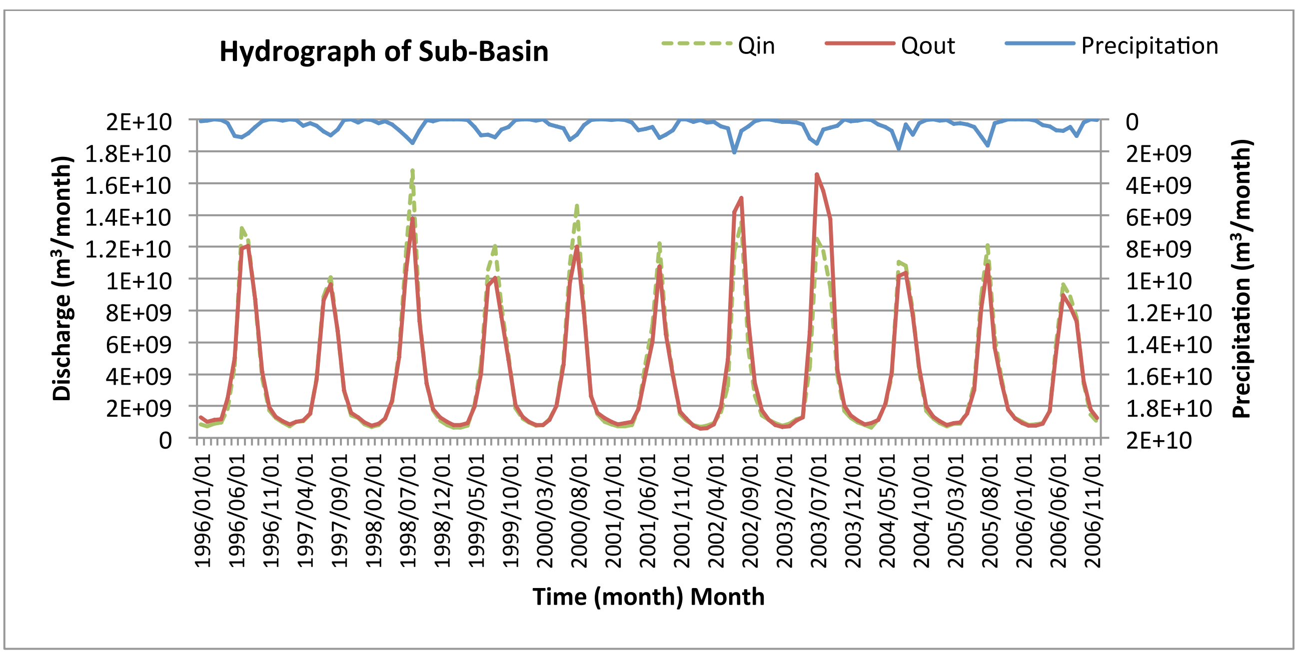


Figure-23: Hydrograph for monthly discharge into and out of sub-basin as well as for precipitation

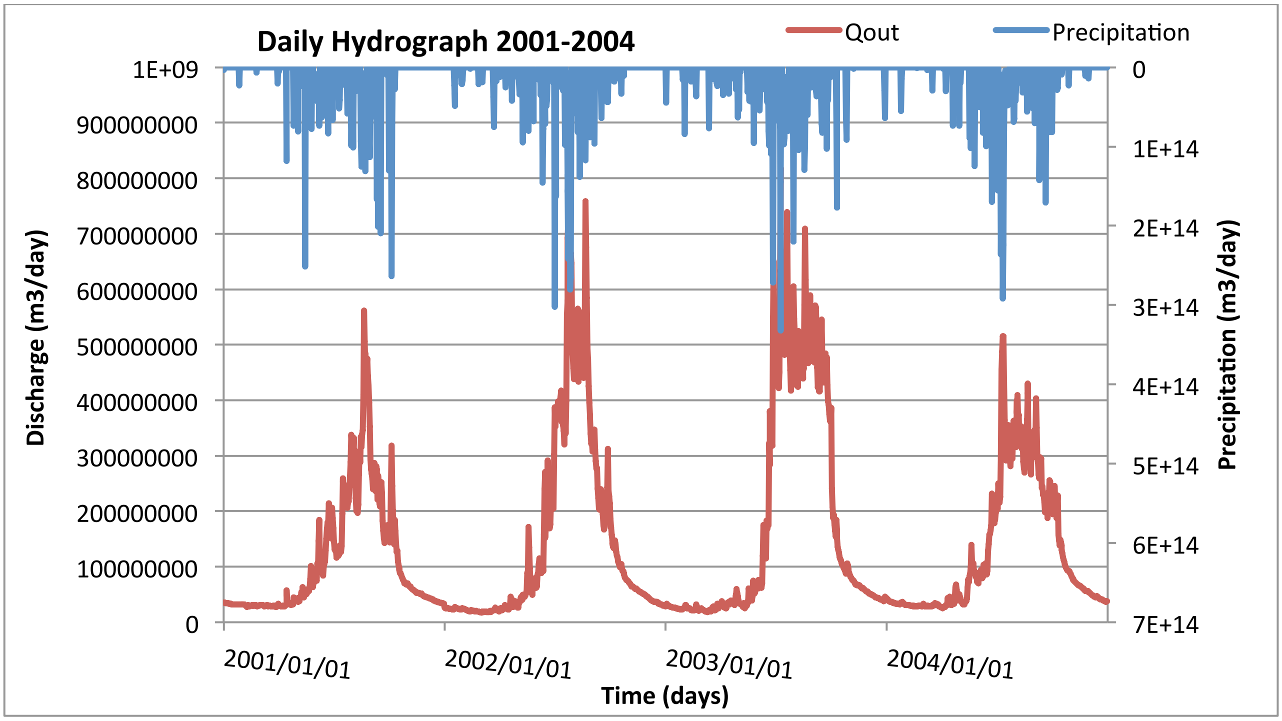


Figure-24: Daily hydrograph for outflow and precipitation in sub-basin for the years 2001-2004

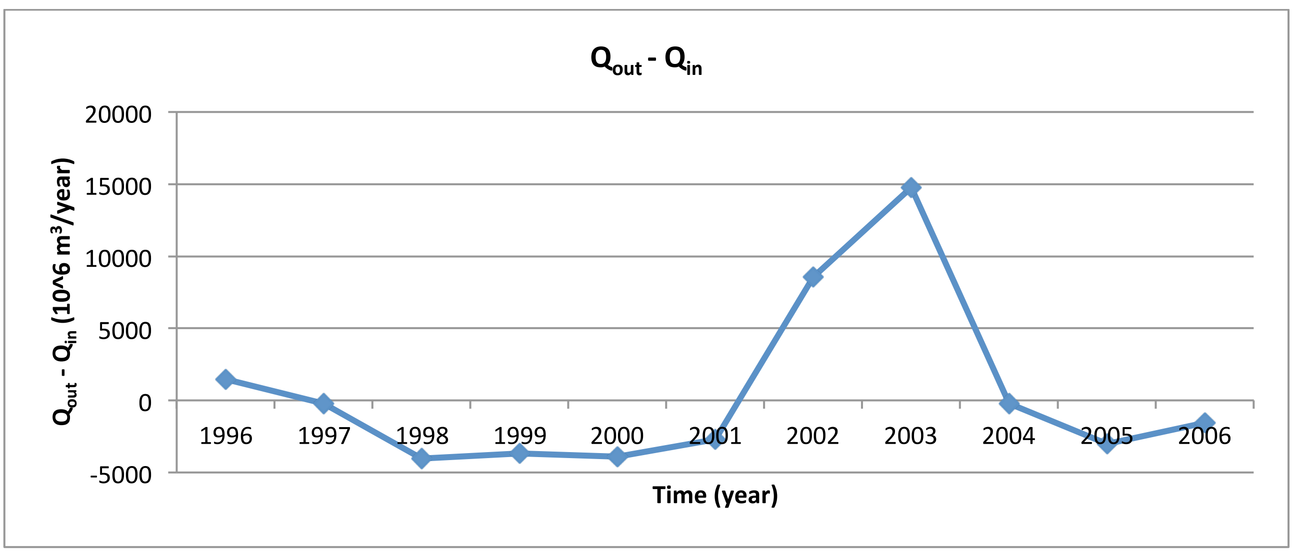


Figure-25: Difference between outflow and inflow of sub-basin over time.

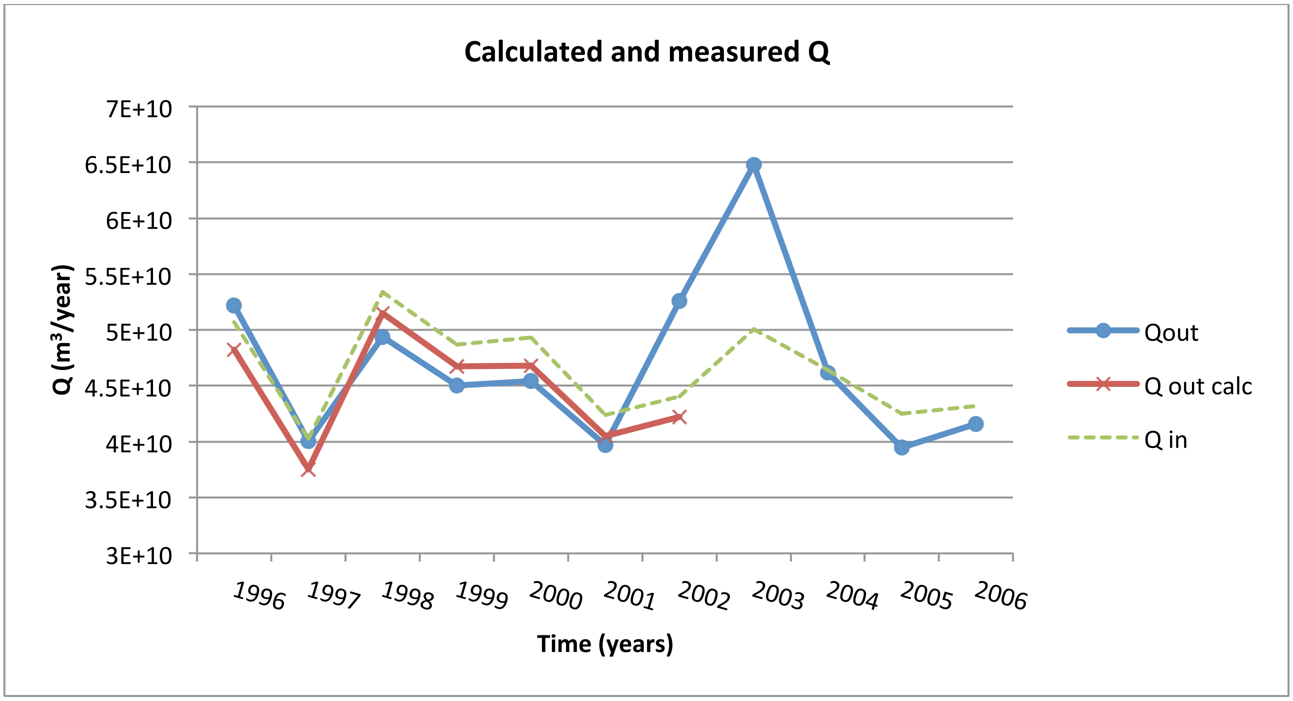


Figure-26: Calculated and measured runoff for the sub-basin

Table-4: Correlation Matrix between the Raingauge Stations

Stations	Okhaldunga	Taplejung	Dhankutta	Biratnagar	Dharan
Okhaldung	1	0.55944	0.3451	0.42464	0.4246
Taplejung	0.55944	1	0.45178	0.4186	0.50846
Dhankutta	0.3451	0.45178	1	0.51272	0.54002
Biratnagar	0.42464	0.4186	0.51272	1	0.51704
Dharan	0.4246	0.50846	0.54002	0.51704	1

RAINFALL V/S DOWNSTREAM FLOW

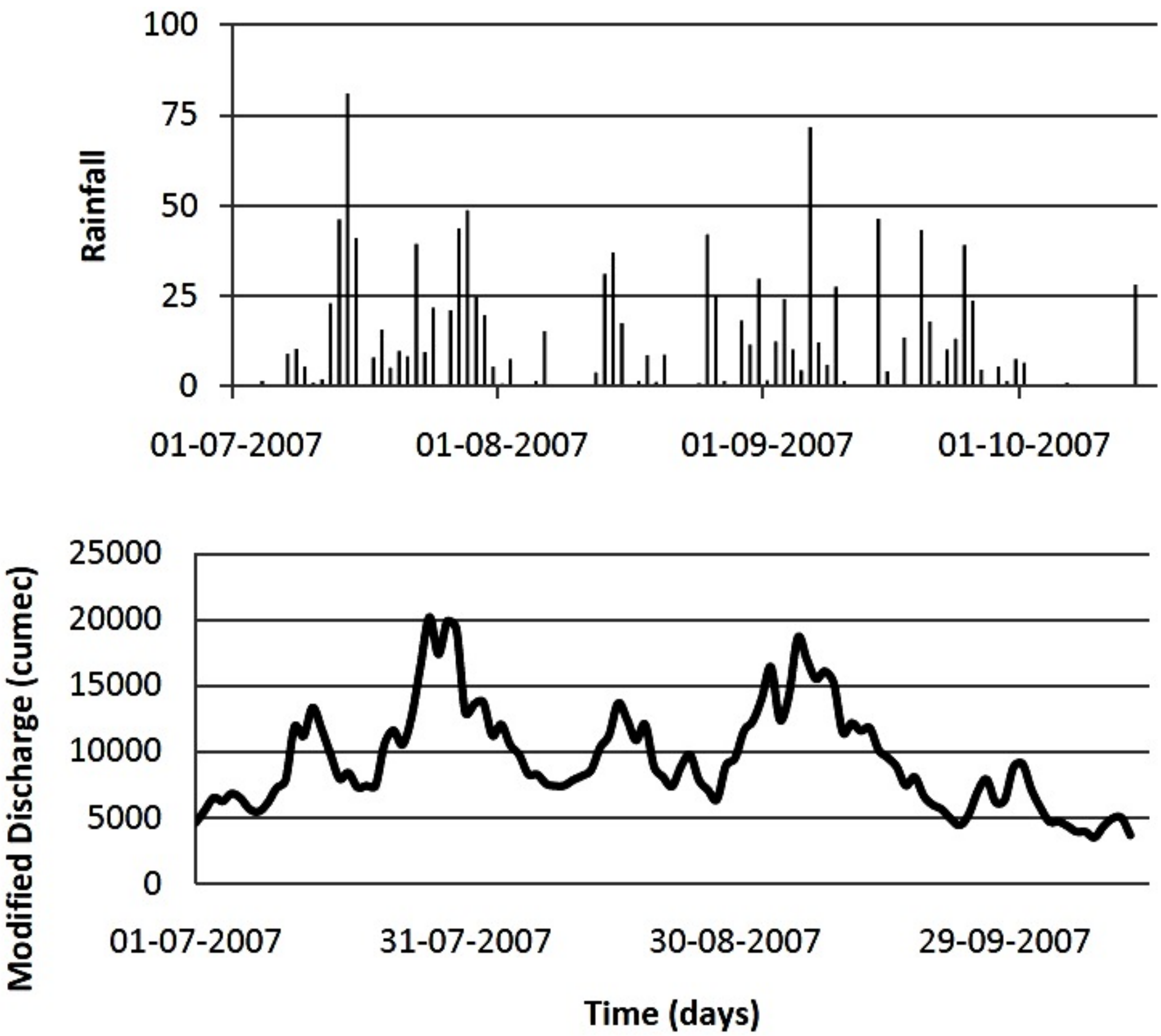


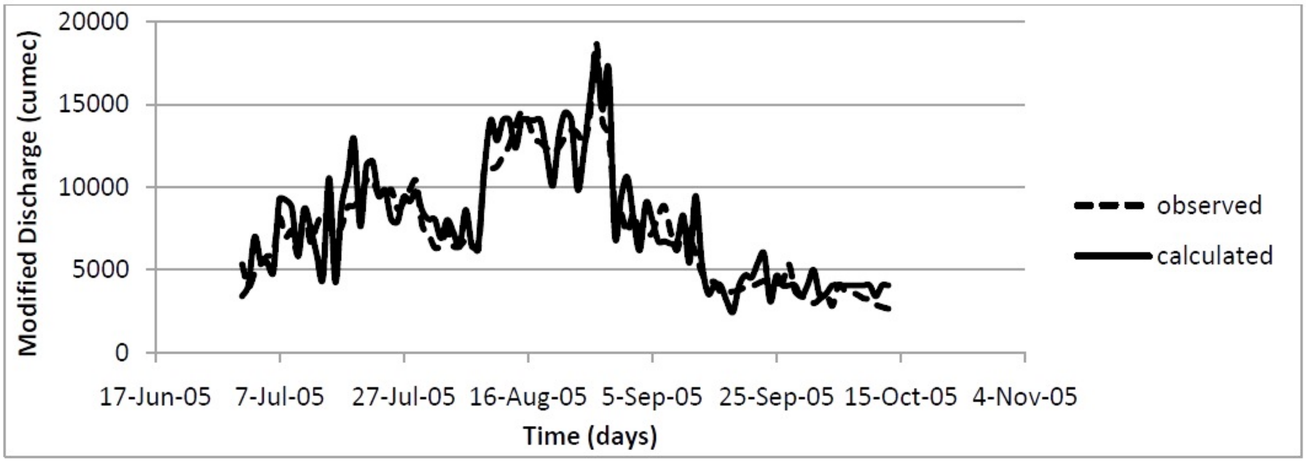
Figure-27: Rainfall v/s Downstream flow in year 2007 on different Rain gauge

(a) Okhaldunga

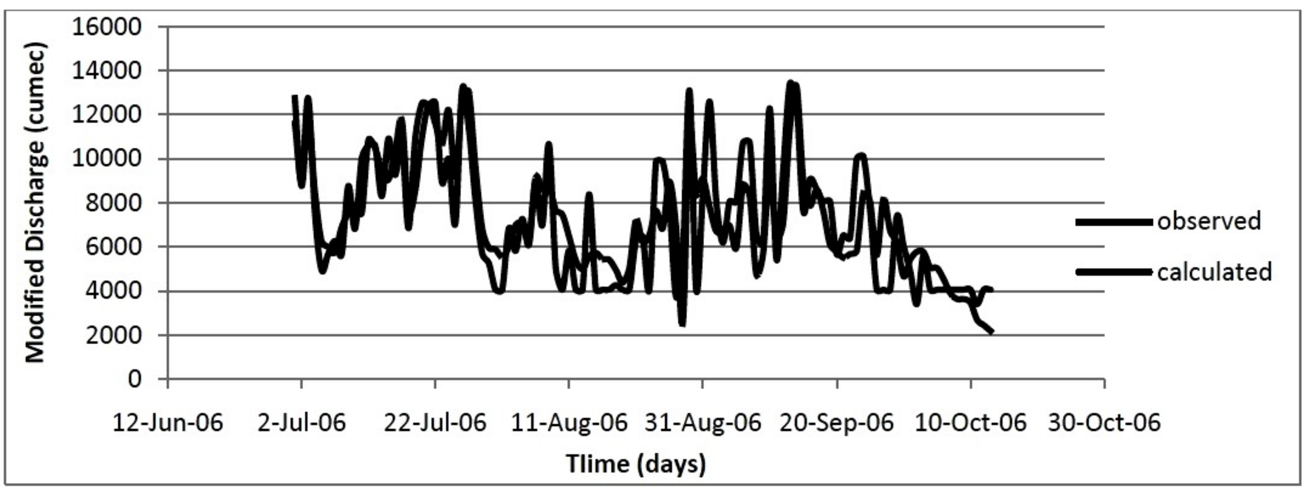
*ANALYSIS BY **SCS-CN** METHOD*

Table-5: R^2 value of the observed and calculated modified discharge by SCS-CN method

Year	2005	2006	2007	2008	2009
R^2	0.8288	0.5256	0.5425	0.4953	0.5103



(a)



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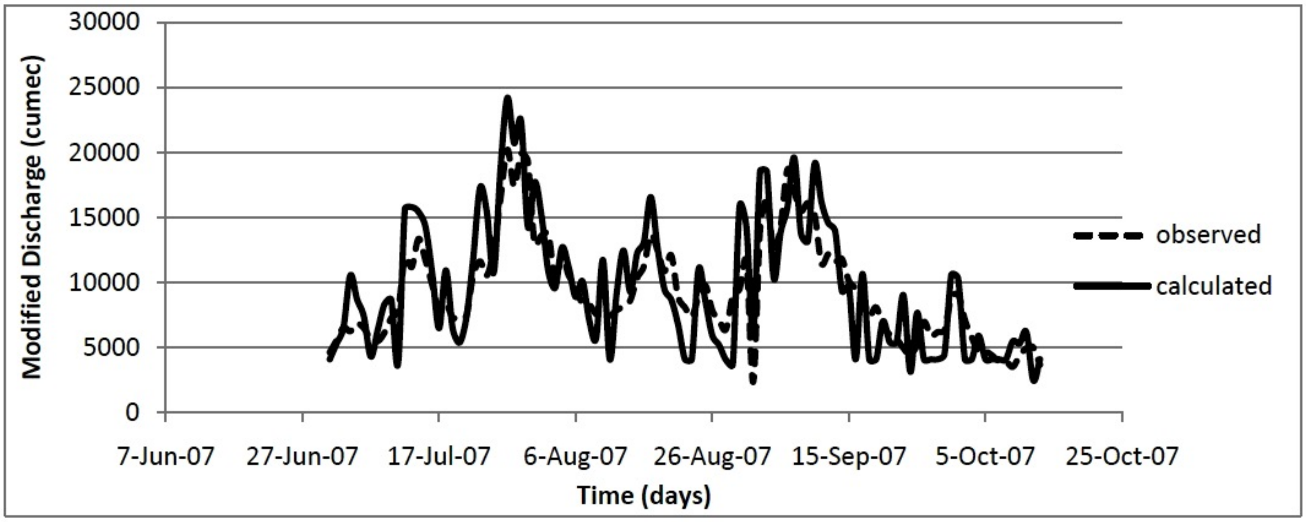

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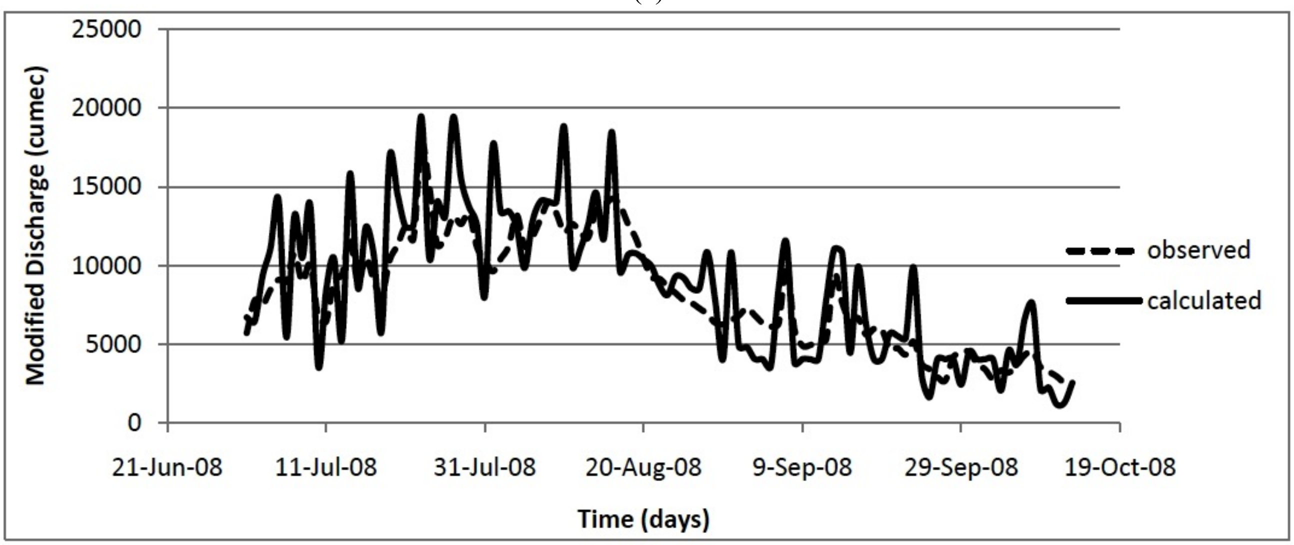

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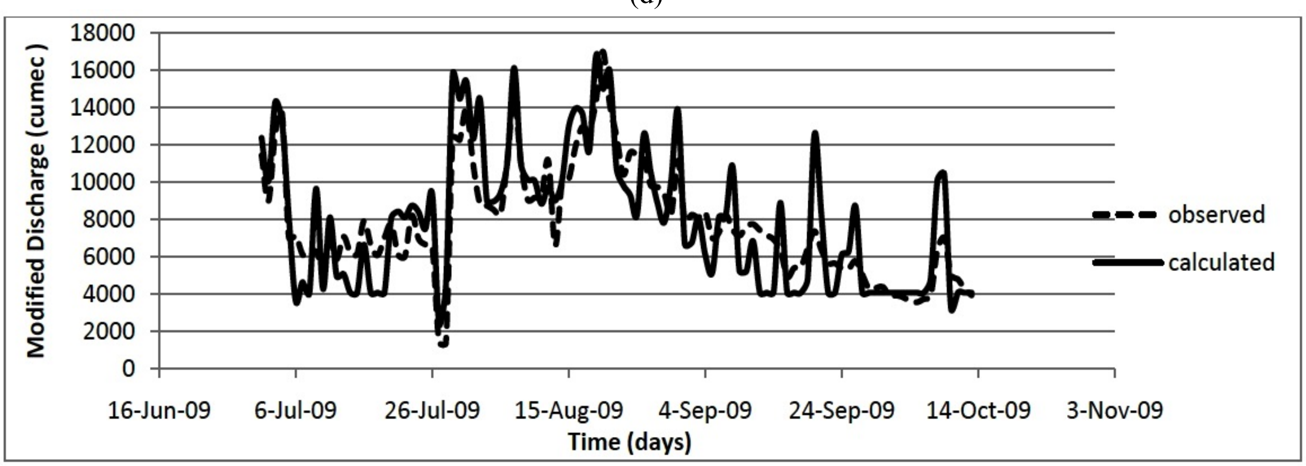
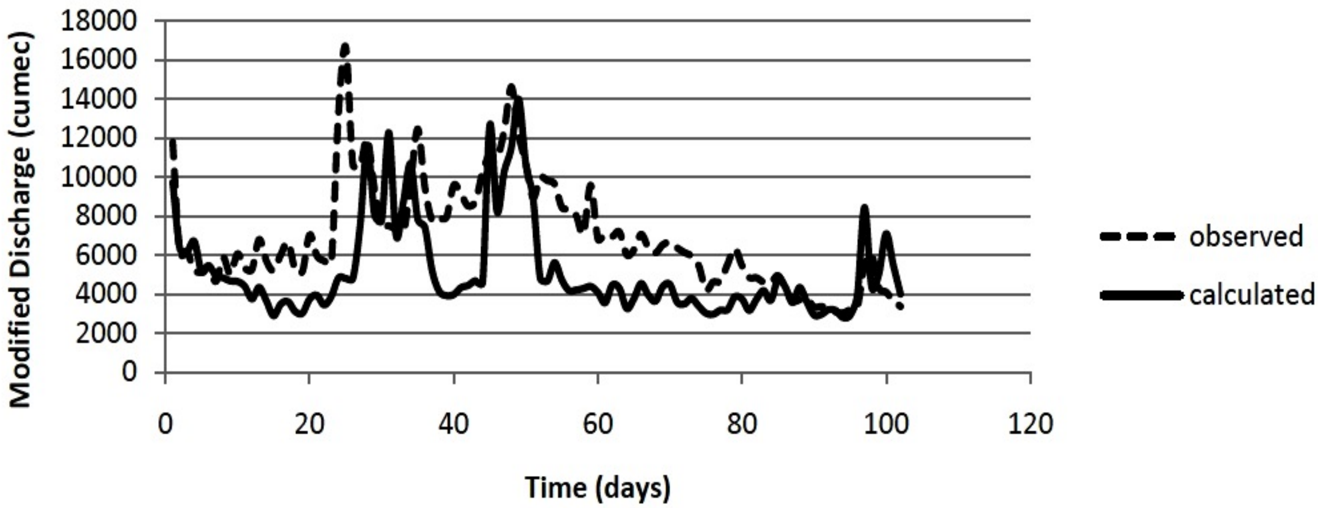


(e)

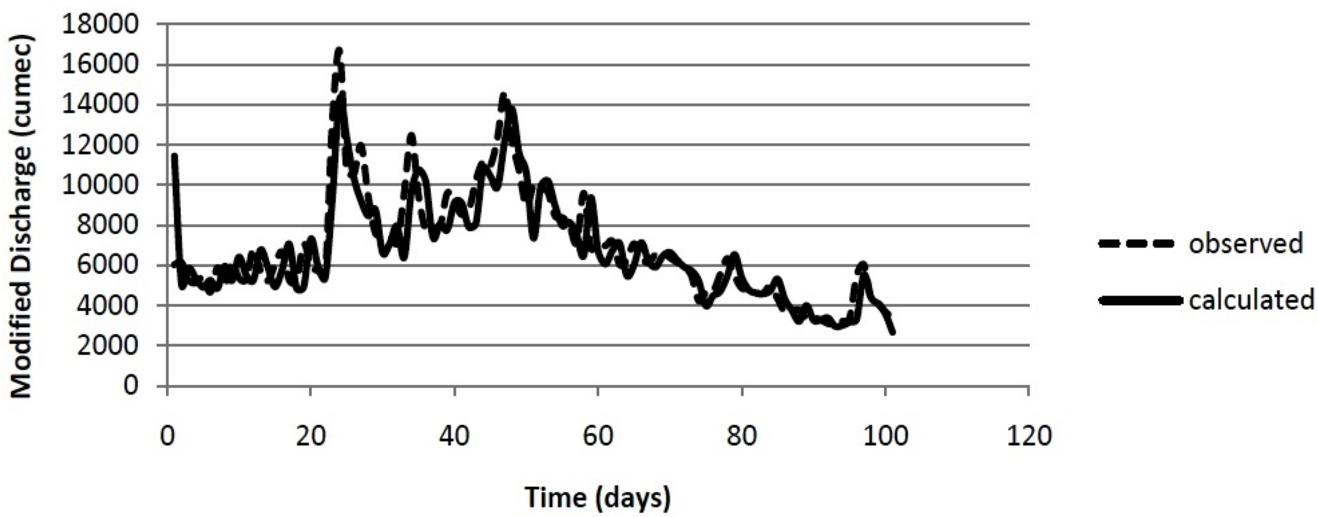
Figure-28: Observed and Calculated Modified Discharge v/s time by SCS-CN method of five years (a)2005, (b)2006, (c)2007, (d)2008 and (e)2009

Table-6: Statistical Parameters of the observed and calculated modified discharge

S.No.	Input	Maximum Difference	Minimum Difference	Average Difference	RMSE	Average R	Average DC
1.	R_t	11853	22	2239	0.1052	0.7012	0.5812
2.	R_{t-1}	12449	34	2675	0.0942	0.7941	0.6861
3.	R_{t-2}	11458	80	1381	0.0812	0.9024	0.8219
4.	R_t & Q_{t-1}	10274	5	1191	0.0734	0.9411	0.8853
5.	R_{t-1} & Q_{t-1}	8780	2	1092	0.0783	0.9558	0.8566
6.	R_{t-2} & Q_{t-1}	6800	33	1080	0.0714	0.9636	0.9157



(a)



(b)

Figure-29: Observed and Calculated Modified Discharge v/s time using ANN

(a) Input R_t, Output Q_t, (b) Input R_{t-2} and Q_{t-1}, Output Q_t

COMPARISON

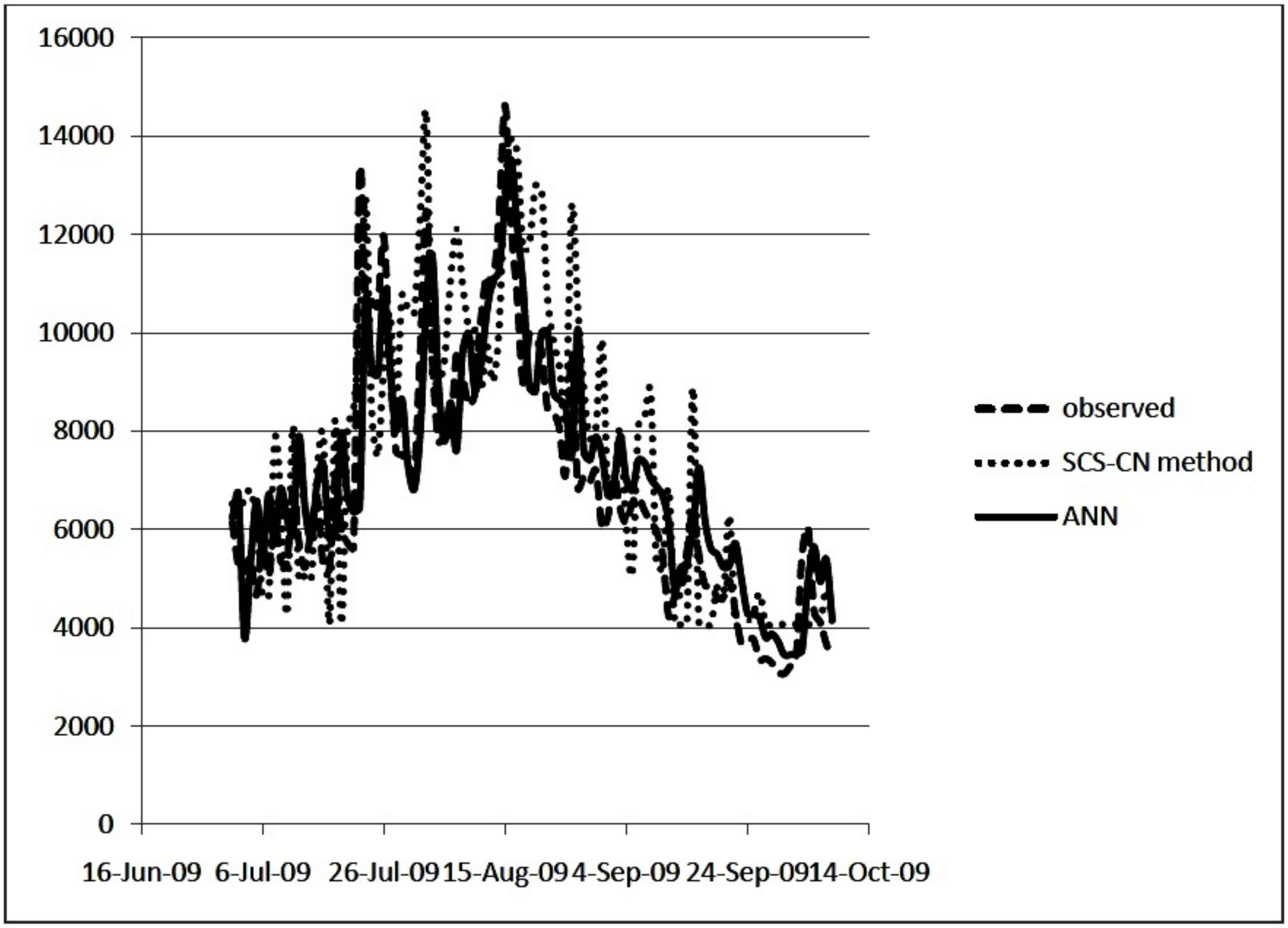


Figure-30: Comparison of two methods for the year 2009

5. CONCLUSION

Based on the analysis performed in Artificial Neural Network and SCS-CN Method following conclusions are drawn:

1. A relationship between upstream and downstream modified flow (Figure 6) has been derived.
2. Correlation between the five different rain gauge stations (Table 4) justify the dependency of the rainfall of other tributaries on the outlet.
3. Time series analysis shows the response of the storm on the discharge station lagged by 1 or 2 days.
4. SCS-CN method considers the infiltration losses and soil properties, so conceptually it is very sound.
5. SCS curve is covering a large area (figure 12) i.e. the modified discharge value coming out to be much higher than the observed value, so for designing purpose it is not economical rather safer.
6. SCS-CN method requires too many field data e.g. topography, Soil type, Moisture condition etc, which are sometimes not known so a lot of assumptions are to be made.
7. ANN required only rainfall and runoff data, and if we have RL of the river bed as input, it will give better solutions.
8. Optimum network possible for daily rainfall-runoff modeling is multi-layer perceptron (MLP).
9. Normalization of data is important for ANN analysis.
10. Selection of transfer function is very important.
11. ANN with two or more input layer gives better results instead using single input layer.
12. As ANN shows satisfactory results in comparison with SCS-CN method, it can be used for prediction of discharge at the remote places where establishment of stations economical.
13. For the learning curve ANN can use both the rainfall and runoff data of previous years while the input parameter in the SCS-CN method can only be rainfall and CN, thus gives better results.
14. If we have large number of data set then SCS-CN method is very good otherwise we can opt for ANN.

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