

Climate Risk Assessment on Dudhkoshi River Basin in terms of Hydropower Potential

Abstract:

Significant obstacles to the production and management of hydropower in hilly basins are presented by climate change. This study looked at how the four hydroelectric projects in Nepal's Dudhkoshi river basin might be affected by climate change and the hazards that come with it. For the common socioeconomic pathway 2-4.5, the output of one GCM, NESM3, was utilized to estimate temperature, precipitation, and consequently discharge in the near future (2031–2045 AD). It is possible to project 96 different scenarios that would represent all four projected climate change cases (warm-dry, warm-wet, cold-wet, and cold-dry), socioeconomic pathways (2-4.5 and 5-8.5), and different time frames (2031-2044 AD, 2061-2074 AD, and 2086-2099 AD) with additional research and fine-tuning of the hydrological model developed from HEC-HMS.

Keywords: Dudhkoshi river basin, Hydrology, Hydropower, Risk, Climate change

Introduction:

The next few decades will be critical in deciding whether we will follow the pathway of RCP 8.5 (catastrophic effects) or lower RCPs (moderate effects). Climate change is an urgent concern. The rise in global temperatures is impacting the global water cycles. Climate change will eventually impact the hydropower industry since hydrological and climatic variables determine hydropower generation and capacity. Additionally, most of the river basins of Nepal are snow-fed basins due to which the hydropower potential is significantly susceptible to climate change. The Saptakoshi River Basin spans three nations and encompasses 60,420 square kilometers, of which 27,883 square kilometers are located in Nepal. Among its seven tributaries, Dudhkoshi occupies 3,712 square kilometers (Nepal S., 2015). Due to the presence of numerous mountain peaks above 8000m, vulnerable glaciers, great hydro-climatic variability, and diverse topography, the Dudhkoshi River basin is a significant river basin of Nepal. This study would utilize the WECCS-Gen tool created by the NDRI Team and would incorporate the skills acquired during the 4-day capacity building workshop organized by the NDRI to assess the risk associated to hydropower potential in terms of change in discharge due to climate change.

Study Area:

The characteristics of the Dudhkoshi River Basin are as follows:

Location	Eastern Nepal, 100 km east of Kathmandu
Origin	Nangpa La Glacier
Area (sq.km)	3712
Elevation Range (masl)	465 (Rabuwā Bazaar) to 8848.86 (Mt.Everest)
Average Elevation (masl)	3800
Ice Covered area	25% of total basin area

This particular basin was chosen because of the low number of studies carried out in this basin and also because a lot of hydropower projects are in the pipeline in this basin.

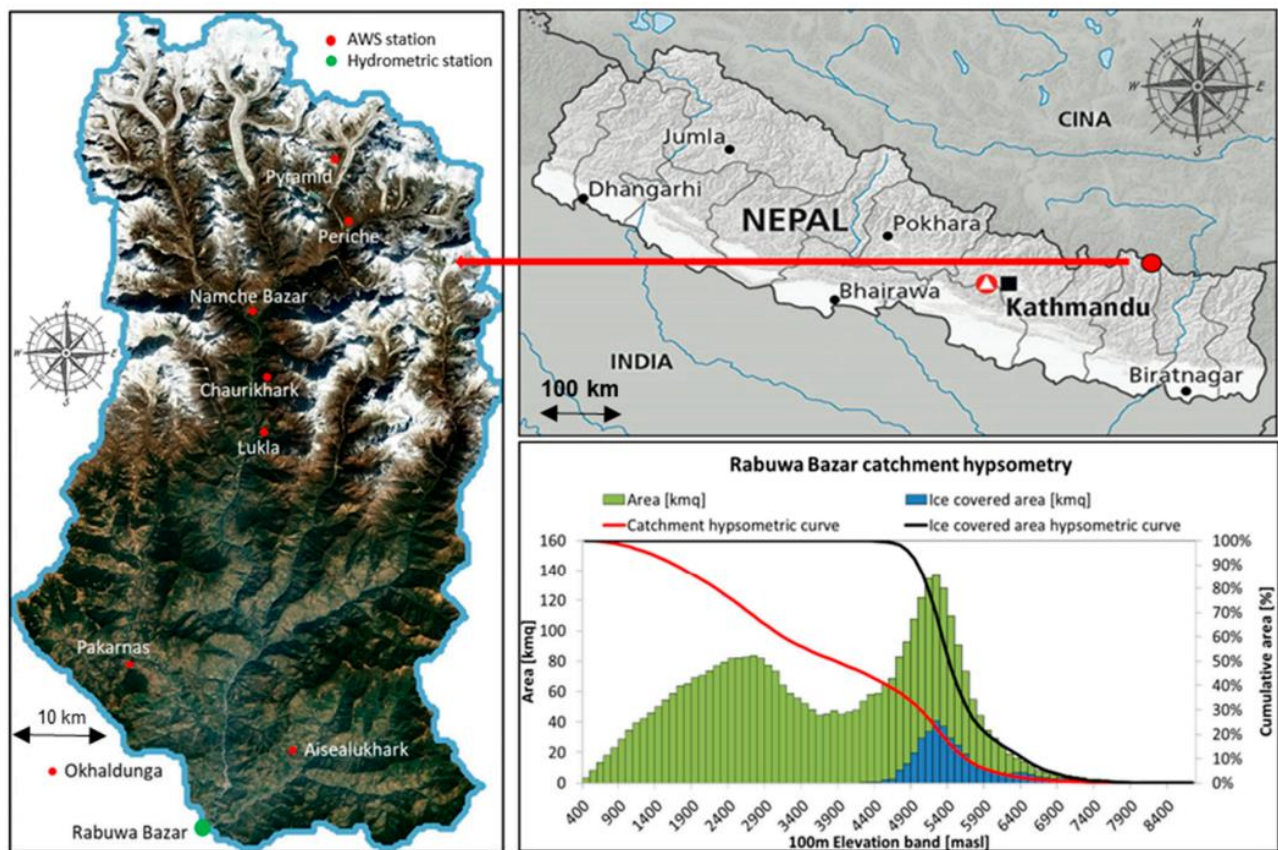


Figure 1. Dudhkoshi Basin (Bocchiola et al., 2020)

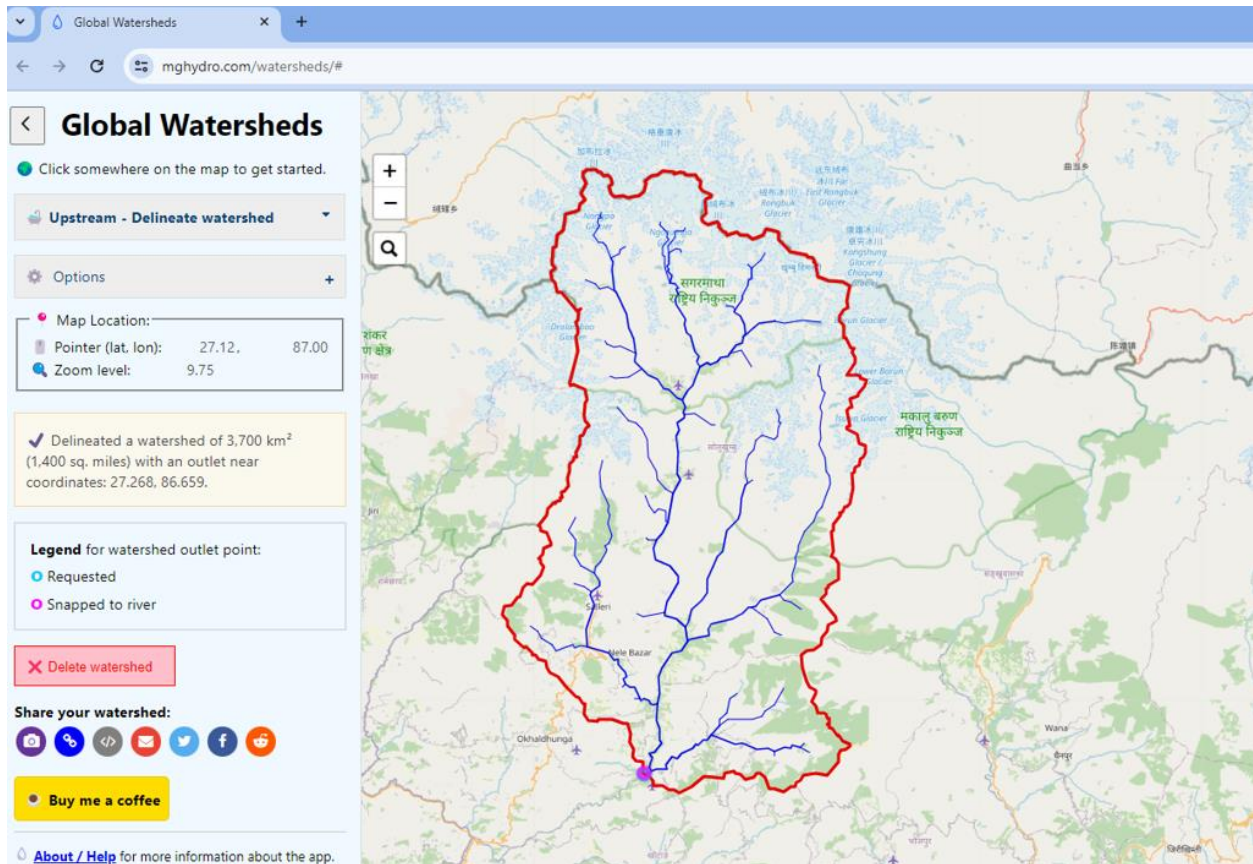


Figure 2. Dudhkoshi Watershed Delineation (Website: mghydro.com)

Some of the hydropower projects that are under construction in the basin, whose discharge are being studied in this study are:

- Dudhkoshi-9 Hydro
- Dudhkoshi-2 Hydro
- Solu Khola Hydro
- Lower Solu Khola Hydro

Data

The data that I used for my study are:

i) Global Climatic Models (GCM):

These are sophisticated tools to simulate Earth's Climate Systems. The atmosphere, seas, land surface, and ice regions are all impacted by physical and chemical processes that are represented by mathematical equations in these models. They play a pivotal role to understand the past, present and future climate conditions.

For my analysis, I used following GCMs to predict future precipitation and temperature in following scenarios:

Projected Climate Change	Model	Shared Socioeconomic Pathways (SSPs)
1) Warm-Dry	NESM3 (China)	2-4.5
		5-8.5
2) Warm-Wet	UKESM1-0-LL	2-4.5
		5-8.5
3) Cold-Wet	EC-Earth3-CC (Europe)	2-4.5
		5-8.5
4) Cold-Dry	MPI-ESM1-2-LR (Germany)	2-4.5
		5-8.5

ii) Global Precipitation Model (GPM):

A Global Precipitation Model (GPM) is a type of numerical model specifically designed to predict precipitation patterns around the world. GPM might have some bias so the bias was corrected with the assistance of the historical data of five hydrological stations of the basin area in my study. GPM was used in my study to acquire observed precipitation from 2001-2014.

iii) ERA-5 Dataset:

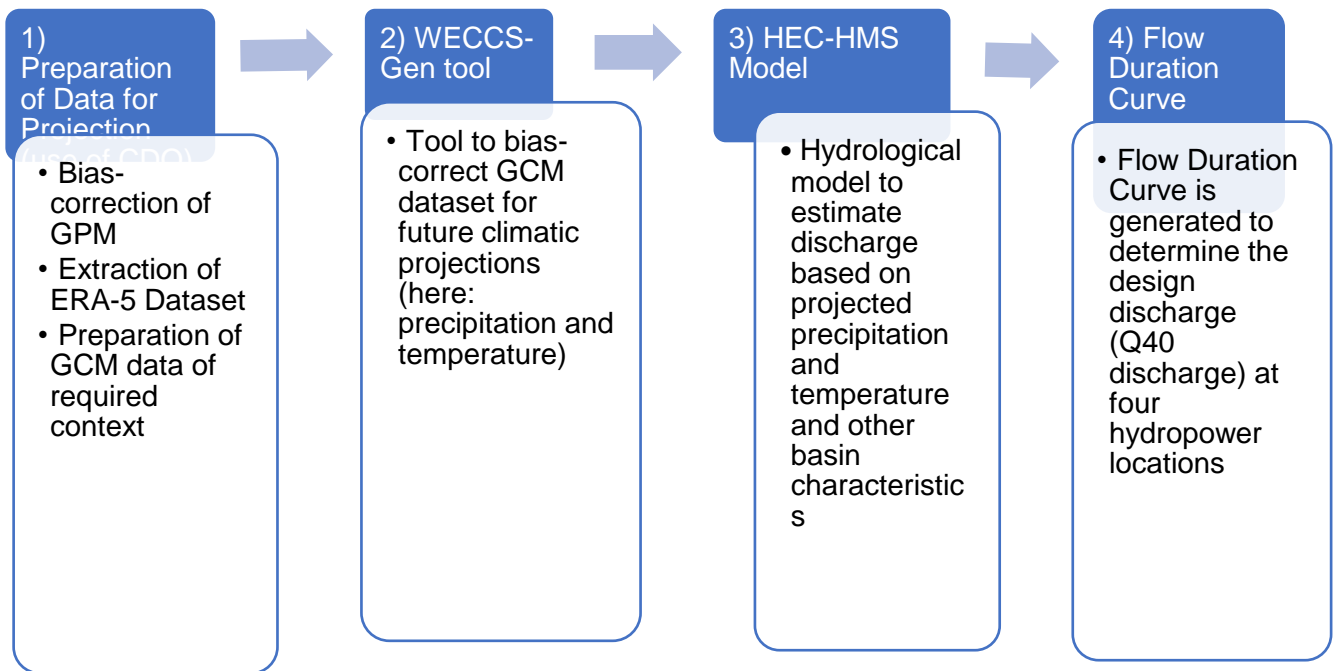
A very detailed global atmospheric reanalysis, known as the ERA5 dataset, was created by the European Centre for Medium-Range Weather Forecasts (ECMWF). It offers hourly estimates of a wide range of atmospheric, land, and oceanic climate variables and is a component of the Copernicus Climate Change Service. ERA-5 was used to acquire past temperature (2001-2014) of the study area.

iv) Department of Hydrology and Meteorology (DHM) Dataset:

GPM was bias corrected by the observed precipitation trends of the DHM. The bias corrected GPM data was then used as the observed data for precipitation. DHM had precipitation data from five stations of the basin which are: Pekarnas, Salleri, Aiselukharka, Chaurikharka, and Okhaldhunga.

In case of temperature, the DHM dataset was incomplete so the ERA-5 dataset was used directly without bias-correction.

Methods



1) Preparation of Data for projections (Use of Climate Data Operator tool)

i) Bias-Correction of GPM dataset:

The GPM dataset was modified using climate data operator tool. Following modifications were made:

- Data reduced to Dudhkoshi Basin Extent
- Data reduced to timeframe 2001-2014
- Data from NetCDF file to table of specific longitude and latitude
- Bias correction factors were computed comparing historical data and GPM data of certain longitude and latitude
- The bias-correction factors were then adjusted to the NetCDF file of GPM

ii) Extraction of ERA-5 Dataset

The ERA-5 dataset was retrieved in hourly basis in .grib format. The file was then converted to .nc file. Average was done and mean temperature was determined for each day. No bias correction was done since there was data unavailability in DHM dataset.

iii) Preparation of GCM Data of required context

Required modifications were made in the GCM datasets. The modifications are:

- Units' conversion
- Hindcast Data clipped to 2001-2014
- Three future scenarios (2031-2044, 2061-74, 2086-2099) observed so the GCMs were clipped to those timeframes.

2) WECCS-Gen Tool

WECCS-Gen Tool is a tool developed by the NDRI team to bias-correct GCM dataset for future climatic projections (here: precipitation and temperature). This tool gave bias corrected spatially disaggregated output.

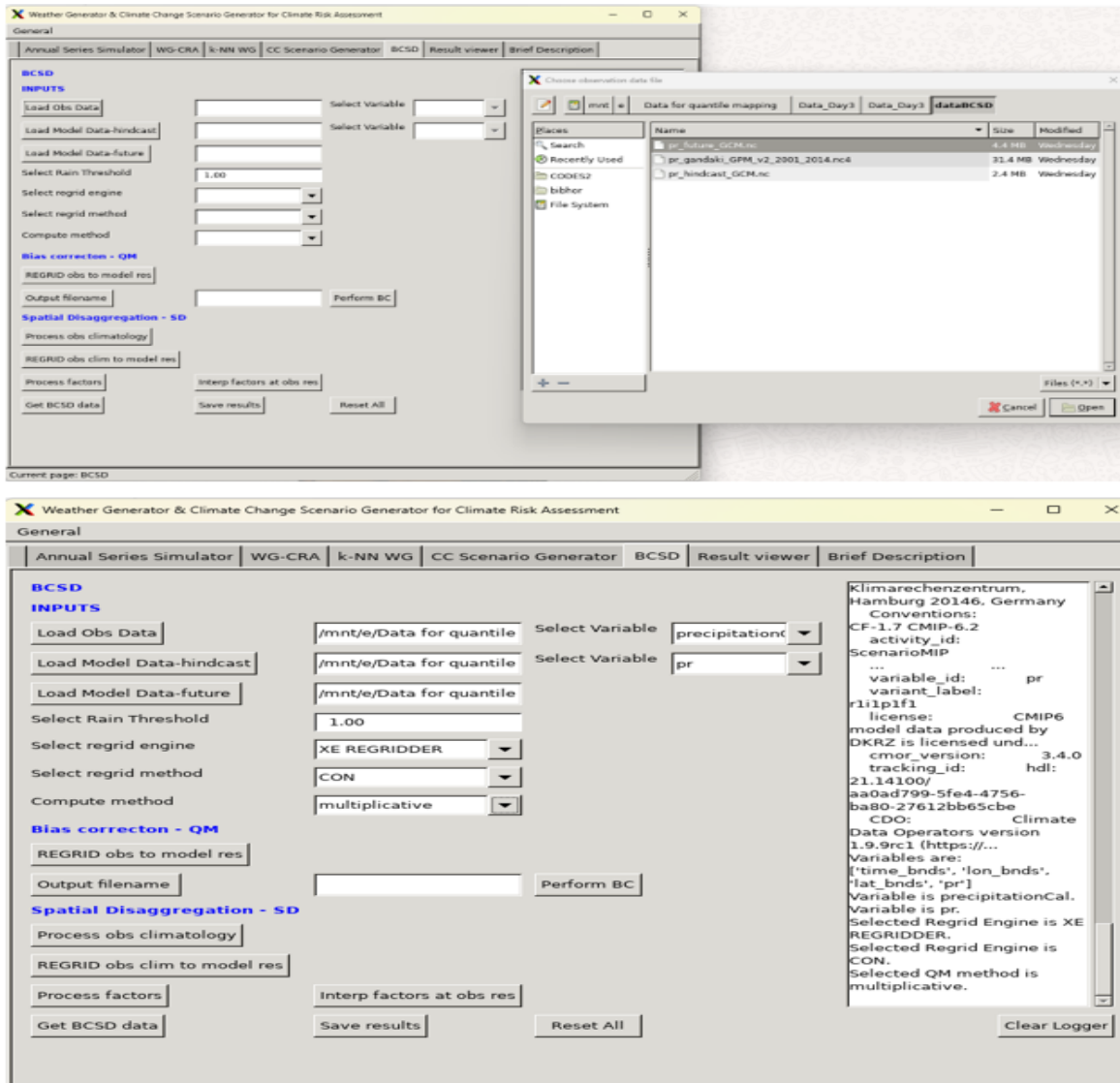


Figure 3 WECCS-Gen Tool

After getting the output .nc file, CDO tool was used to clip date and determine the weighted average values of precipitation and temperature.

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Figure 4. Use of CDO tool to determine weighted average of precipitation and temperature of each subbasin

A	B	C	D	E	F	G
date	Subbasin-01,	Subbasin-04,	Subbasin-05,	Subbasin-02,	Subbasin-03,	Subbasin-06,
1/1/2031 12:00	-4.5658	1.133	3.5225	-1.3087	-1.0667	3.0655
1/2/2031 12:00	-9.6501	2.3186	7.3463	-2.8146	-2.3002	6.389
1/3/2031 12:00	-7.8692	1.833	5.9153	-2.3318	-1.91	5.1413
1/4/2031 12:00	0	0	0	0	0	0
1/5/2031 12:00	0	0	0	0	0	0
1/6/2031 12:00	-4.0132	0.8583	2.9178	-1.2378	-1.0186	2.5324
1/7/2031 12:00	-6.6189	1.3801	4.7667	-2.064	-1.7003	4.1352
1/8/2031 12:00	0	0	0	0	0	0
1/9/2031 12:00	0	0	0	0	0	0
1/10/2031 12:00	-0.8028	0.1569	0.5649	-0.2571	-0.2122	0.4895
1/11/2031 12:00	-0.0849	0.0163	0.0594	-0.0274	-0.0226	0.0515
1/12/2031 12:00	-10.3582	1.9584	7.2067	-3.3582	-2.7719	6.2409
1/13/2031 12:00	-11.2757	2.1037	7.8112	-3.6737	-3.0316	6.7629
1/14/2031 12:00	-8.3511	1.5414	5.7645	-2.7315	-2.2537	4.99
1/15/2031 12:00	-4.2661	0.7805	2.9372	-1.3998	-1.1543	2.5421
1/16/2031 12:00	0	0	0	0	0	0
1/17/2031 12:00	-13.8571	2.5095	9.5169	-4.5643	-3.7577	8.2343
1/18/2031 12:00	-18.3551	3.32	12.6058	-6.0485	-4.9742	10.9071
1/19/2031 12:00	-17.3689	3.144	11.9401	-5.7231	-4.7007	10.3308
1/20/2031 12:00	-14.3515	2.6061	9.8822	-4.7244	-3.8747	8.5504
1/21/2031 12:00	-8.6013	1.5708	5.9377	-2.8262	-2.3144	5.1378
1/22/2031 12:00	-17.3345	3.1903	12.0074	-5.6814	-4.6442	10.3898
1/23/2031 12:00	-22.1287	4.1145	15.3933	-7.2277	-5.8967	13.3214
1/24/2031 12:00	-24.0232	4.52	16.7932	-7.8146	-6.3612	14.5355
1/25/2031 12:00	-18.4649	3.5245	12.9843	-5.9764	-4.8534	11.24
1/26/2031 12:00	-15.9948	3.1018	11.3219	-5.1478	-4.1688	9.8034
1/27/2031 12:00	-19.0014	3.7519	13.5489	-6.0755	-4.9071	11.734
1/28/2031 12:00	-22.1655	4.4627	15.933	-7.0361	-5.6652	13.8018
wavg_ssp245_2031-44						

Figure 5. Data from the .csv was entered into the HEC-HMS model

3) Creation of HEC-HMS Model

The US Army Corps of Engineers created the extensive hydrologic modeling system known as HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System). It is frequently used for planning, designing, and managing water resources projects. It is intended to mimic the precipitation-runoff processes of dendritic watershed systems.

Watershed was created in the software. Basin characteristics and climatic variables like precipitation and temperature after doing weighted average were fit into the model to imitate the actual watershed. The final output was the discharge and it was observed at four hydropower locations.

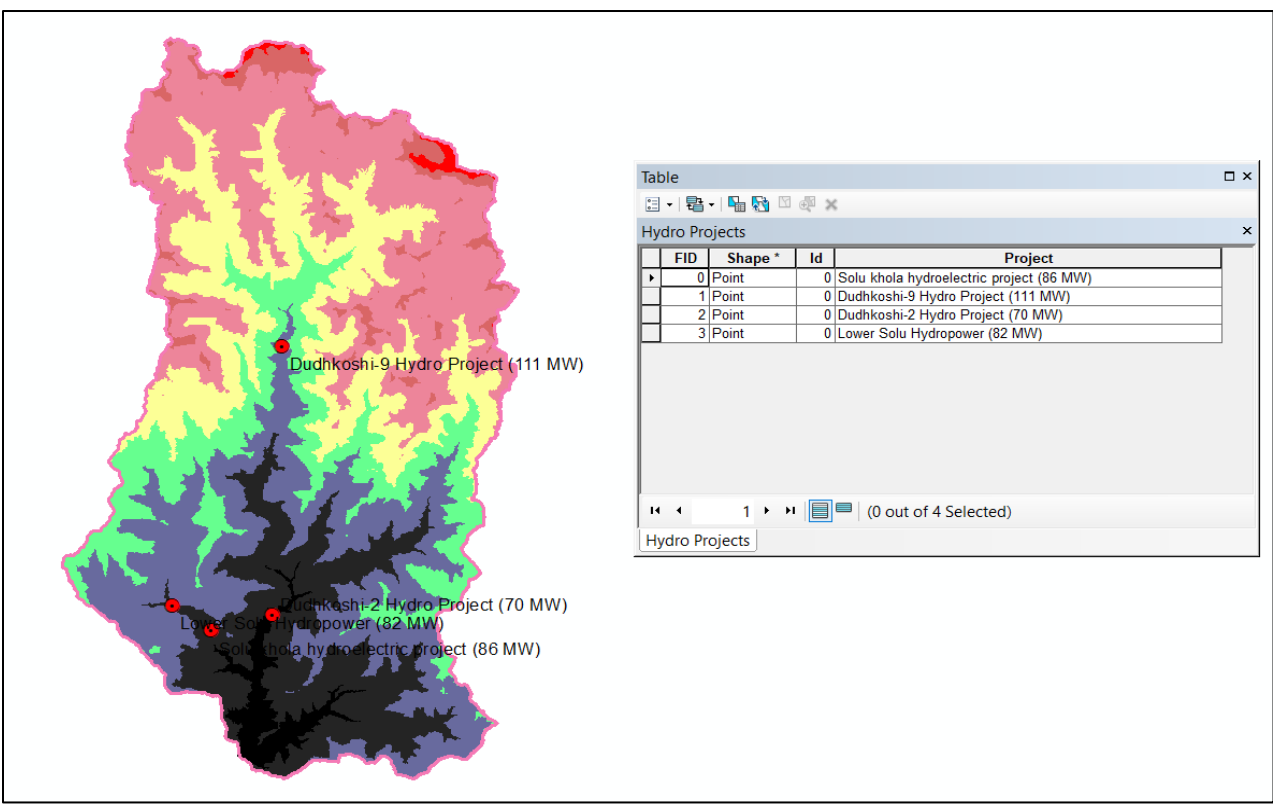
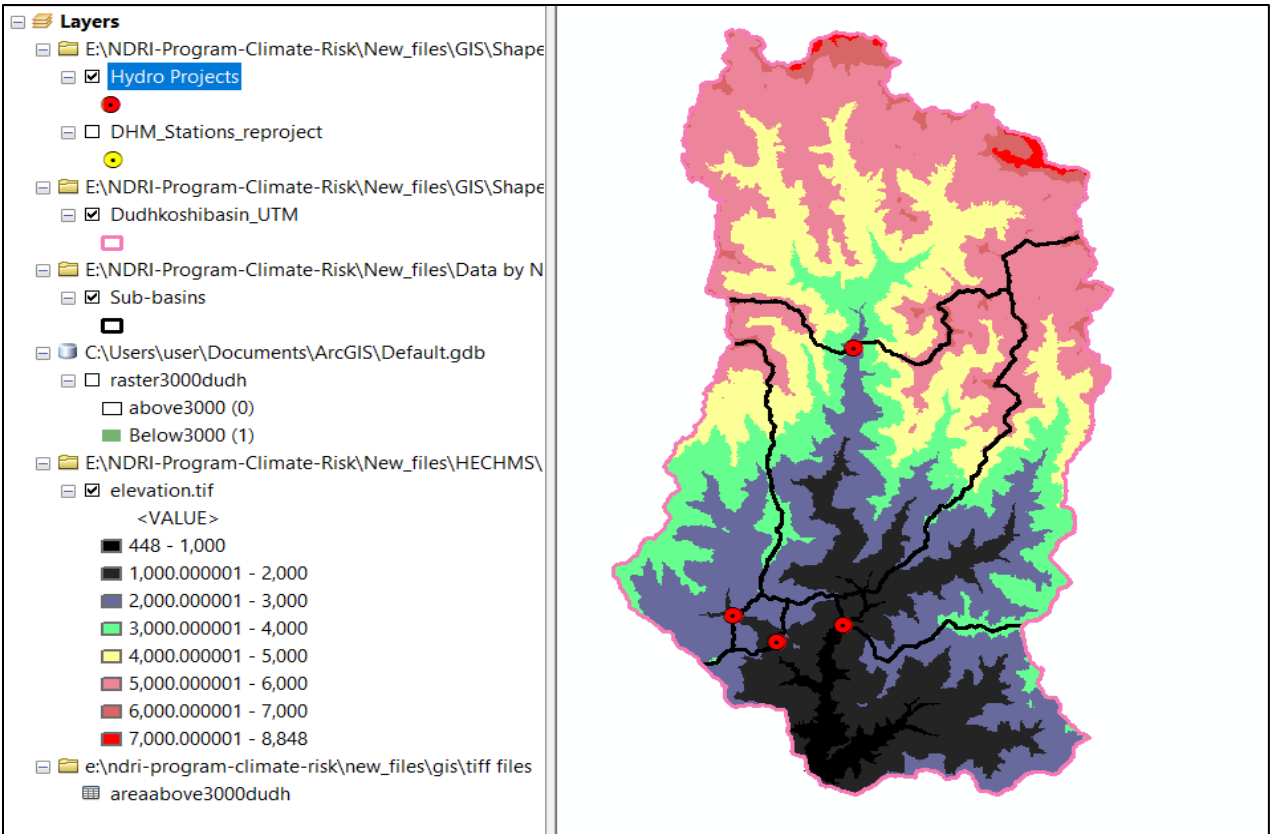


Figure 6 Four hydropower locations tracked in Arcmap

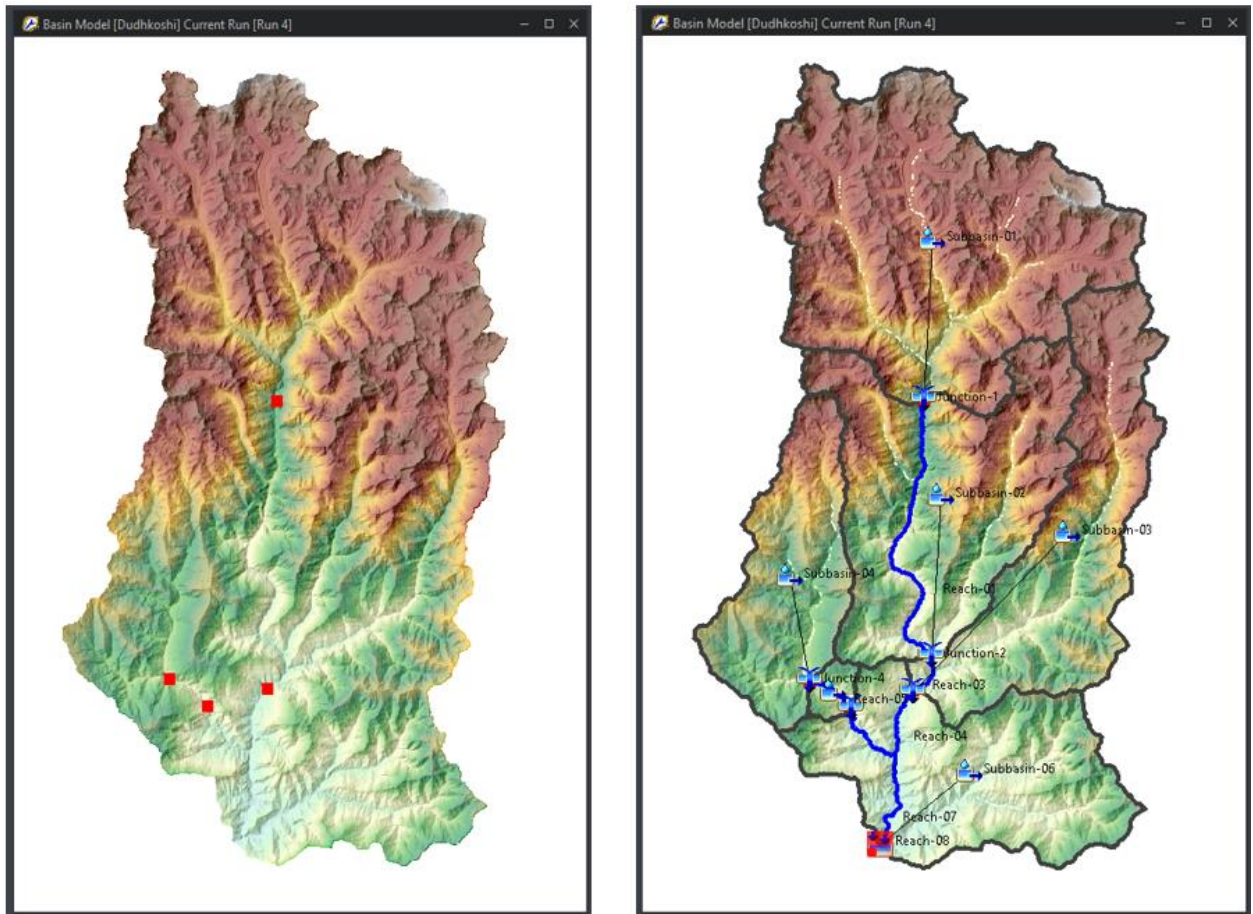


Figure 7 Junctions creation in HEC-HMS Model

Junctions were created where discharge needed to be computed.

- Junction 1 = Dudhkoshi-9
- Junction 3 = Dudhkoshi-2
- Junction 4 = Lower Solu
- Junction 5 = Solukhola Hydro

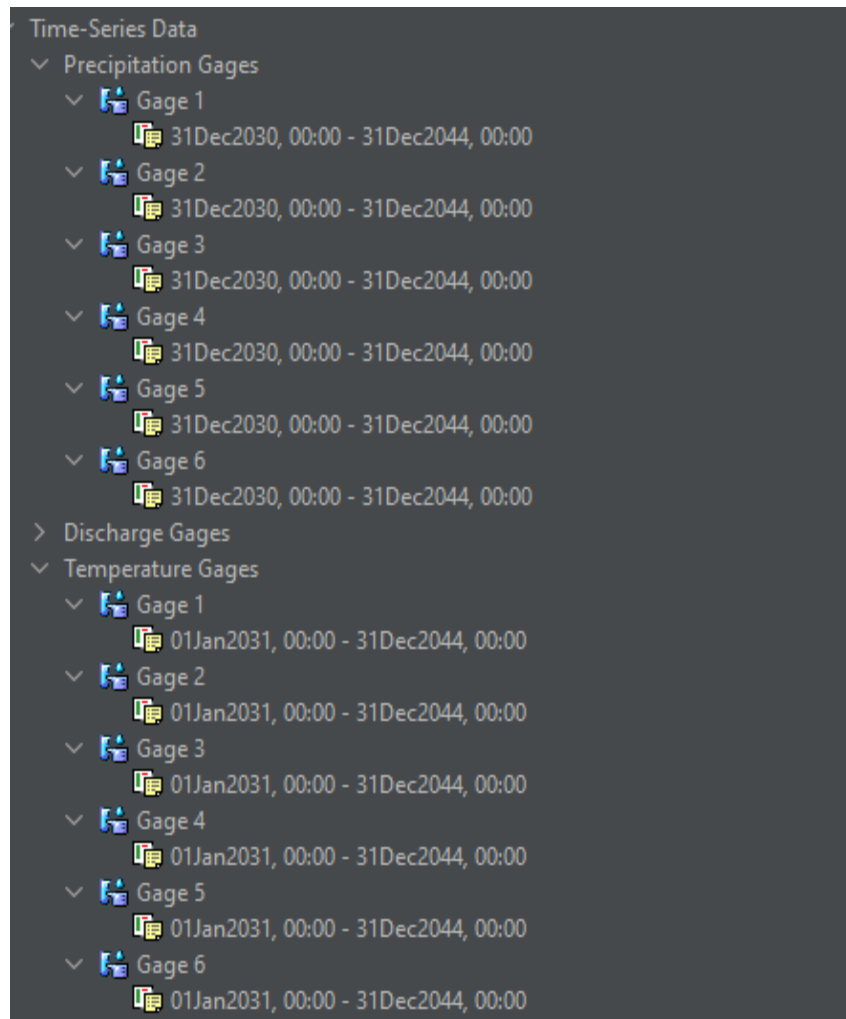


Figure 8 Precipitation and temperature data entered as time-series data

4) Flow Duration Curve:

An essential tool in hydrology for illustrating the relationship between streamflow frequency and magnitude is the flow duration curve (FDC). It displays the proportion of time that a stream's flow is expected to reach or surpass a given value. In hydropower projects, Q40 is taken as the design discharge.

Results:

The hydrological model developed from the HEC-HMS tool shows following characteristics:

Stage	Percentage Replication (%)
1) Calibration	71.3
2) Validation	69

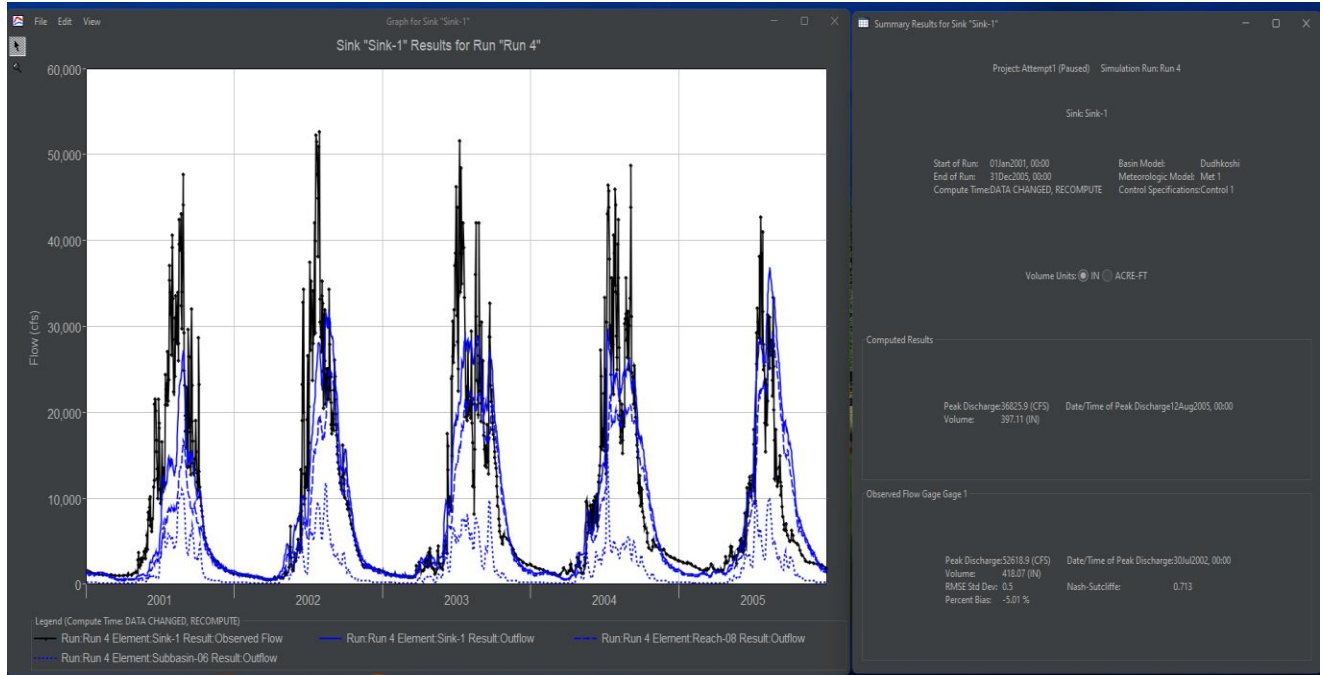


Figure 9 Calibration of the Model

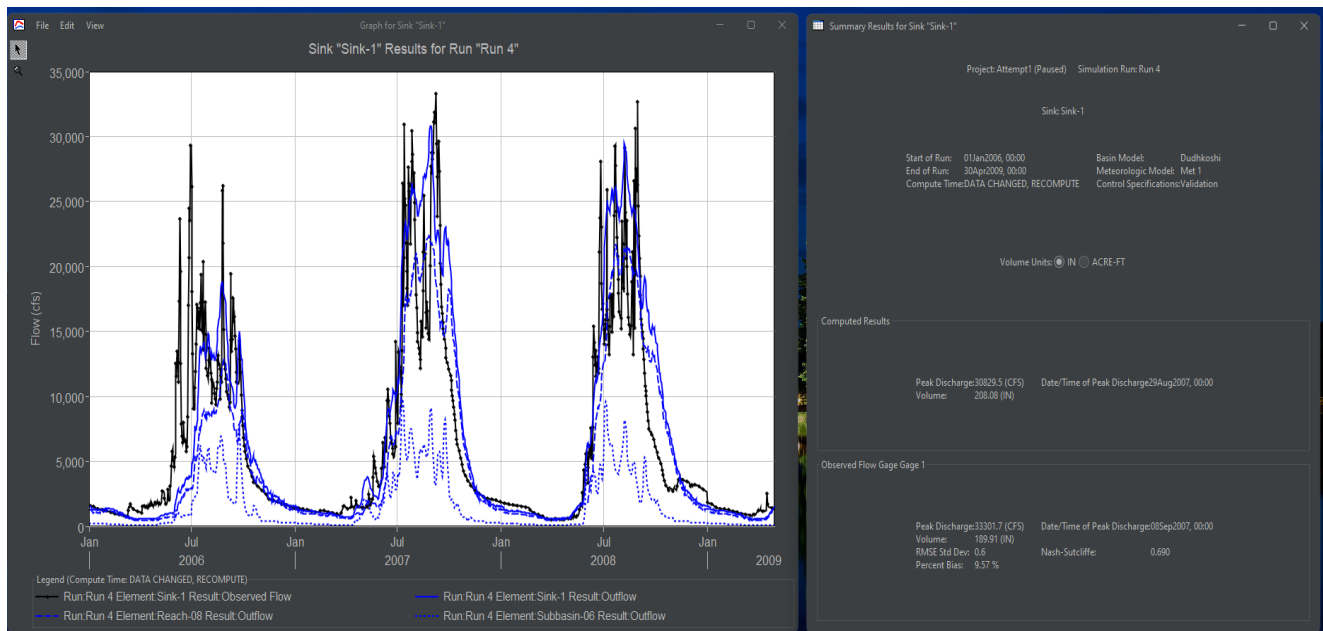


Figure 10. Validation of the Model

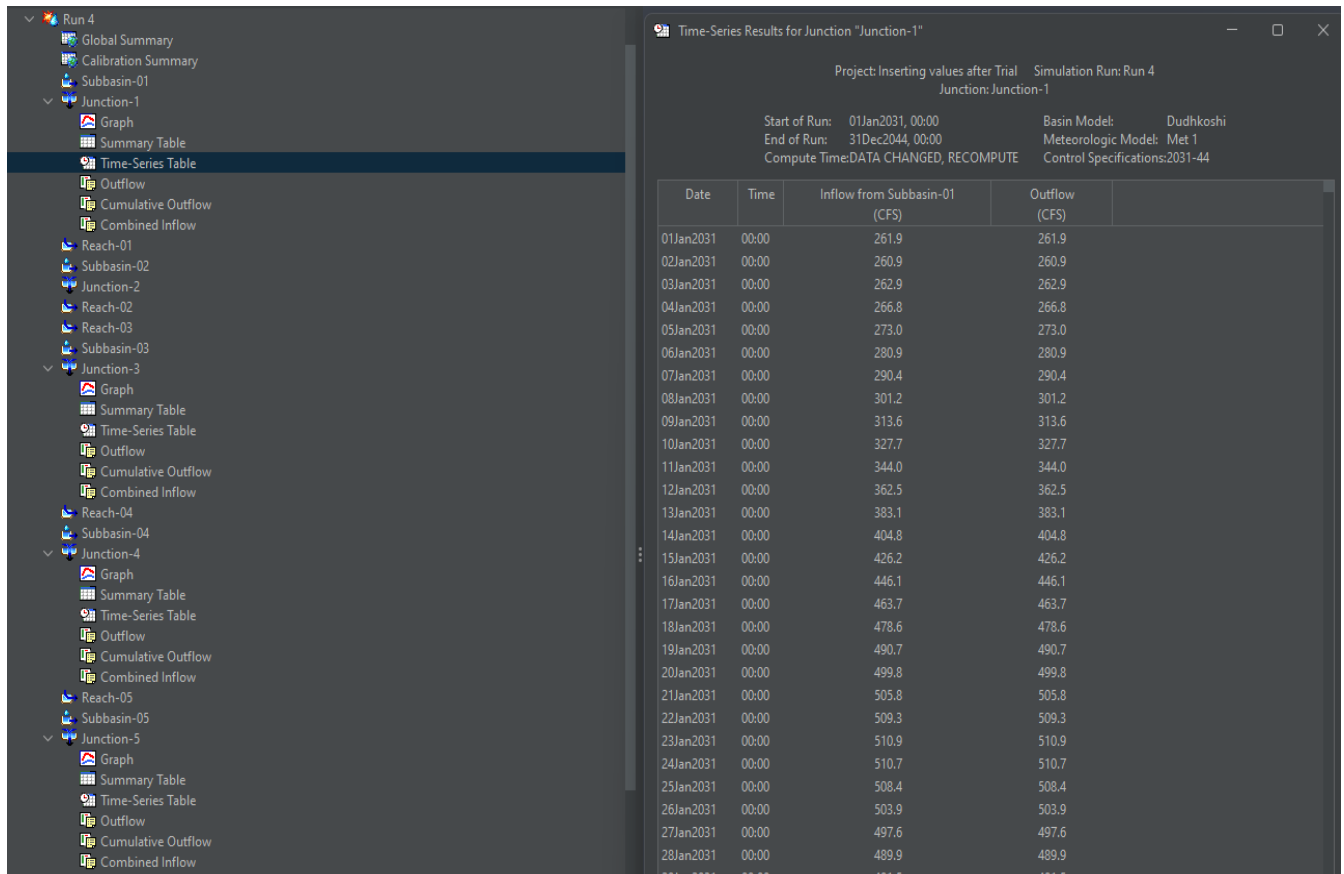


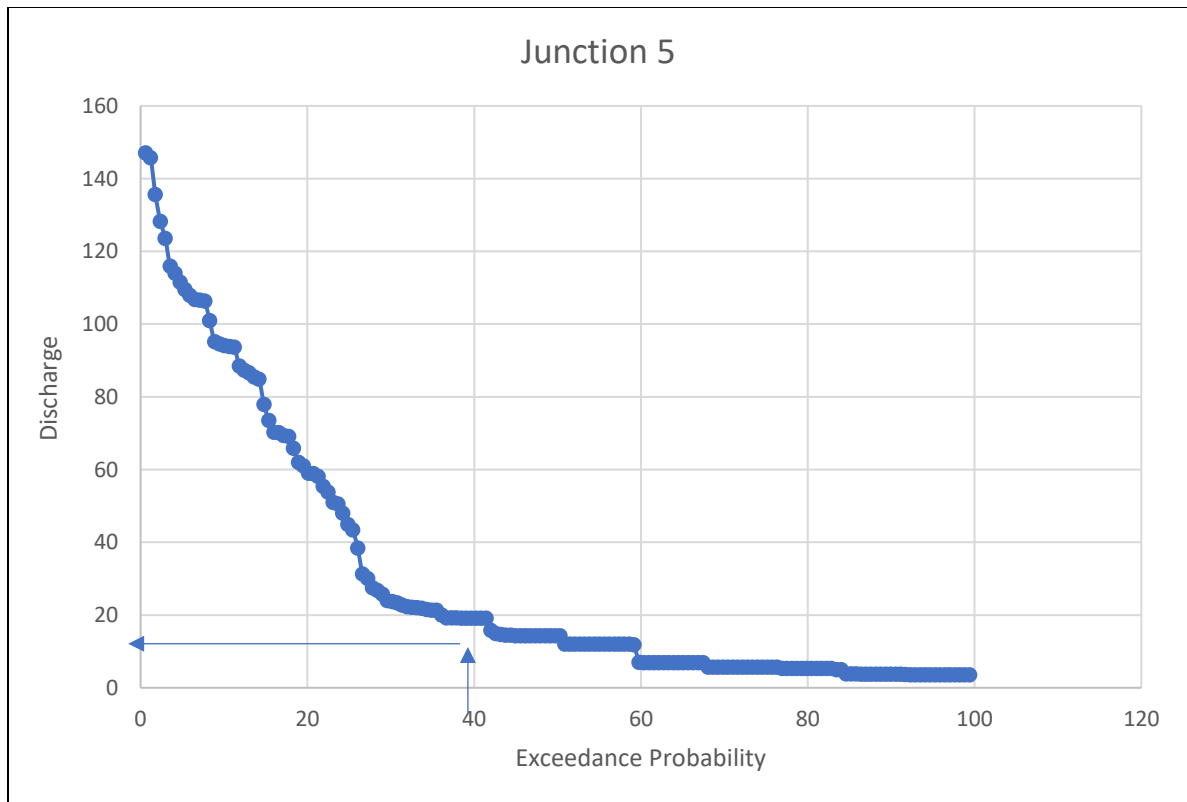
Figure 11. Discharge computed at respective junction when time series data inserted

Some of the outputs are: (Example: NESM3 GCM Model, SSP 245, 2031-44 AD)

Hydro Project	Q40 design (m3/s)	Q40 Prediction (m3/s)
1) Solu Khola (Junction 5)	17.05	18
2) Lower Solu Khola (Junction 4)	11.3	12
3) Dudhkoshi-2 (Junction 3)	62.3	49
4) Dudhkoshi-9 (Junction 1)	49.6	19

Salient Features:

S.N.	Components	Description
1	Project Location	Solukhumbu District, Province 1
	Intake Site	Solududhkunda Municipality
	Powerhouse Area	Thulung Dudhkoshi Gaupalika
	Latitude	27°21'53"N to 27°25'15"N
	Longitude	86°37'35"E to 86°41'15"E
2	General	
	Name of River	Solu Khola
	Type of Scheme	Run-of-River
	Gross Head	613.20 m
	Net Head	598.09 m
	Installed Capacity	86,000 kW
3	Hydrology	
	Catchment Area	454 km ²
	Design Discharge	17.05 m ³ /s
	Design Flood Discharge	475 m ³ /s (100 Yr. Flood)
4	Diversion Weir	
	Type of Weir	Gravity free flow concrete
	Length of Weir	34.8 m
	Max. Height of Weir	13.50 m from foundation level
	Crest Elevation	EL. 1,262.00 masl



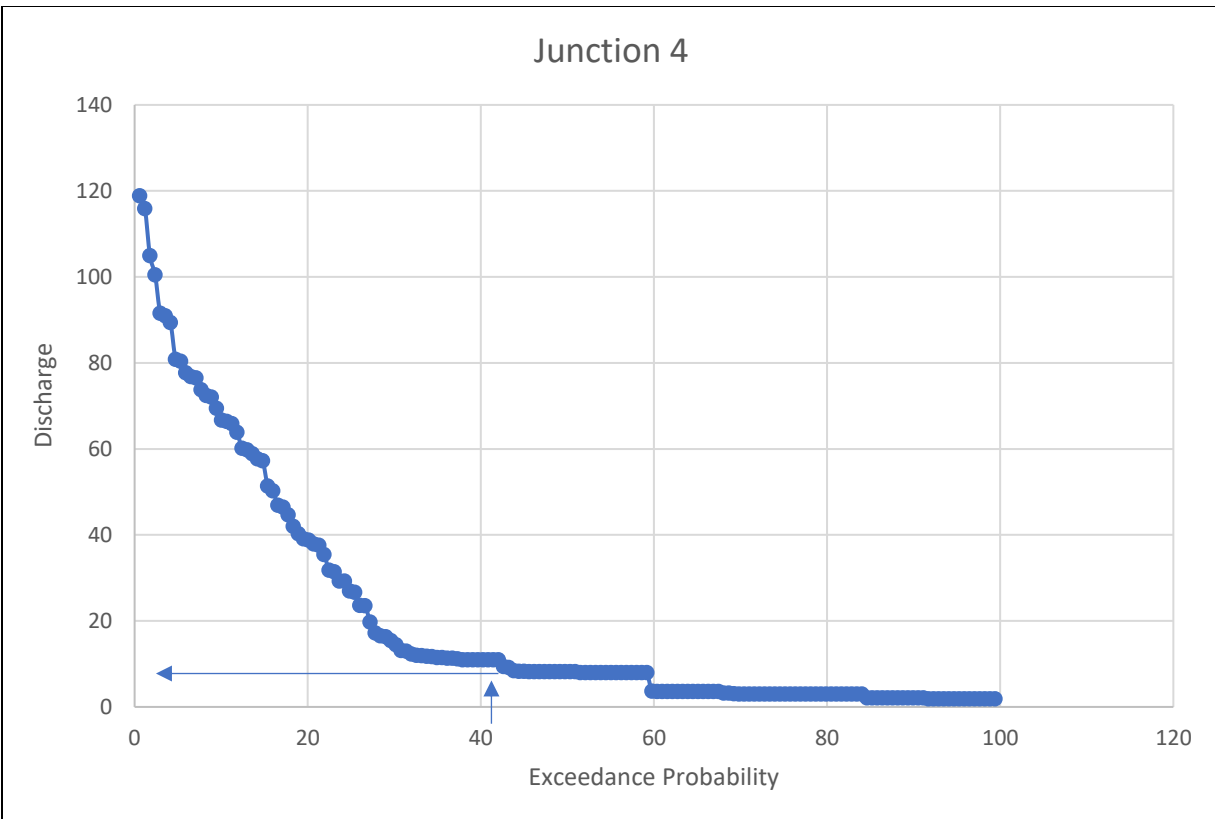
SALIENT FEATURES OF LOWER SOLU KHOLA SMALL HYDROPOWER PROJECT

1. Location

District	Solukhumbu
Geographical Location	Between Latitudes 27° 25' 29" N and 27° 26' 30" N Longitudes 86° 35' 29" E and 86° 37' 07" E

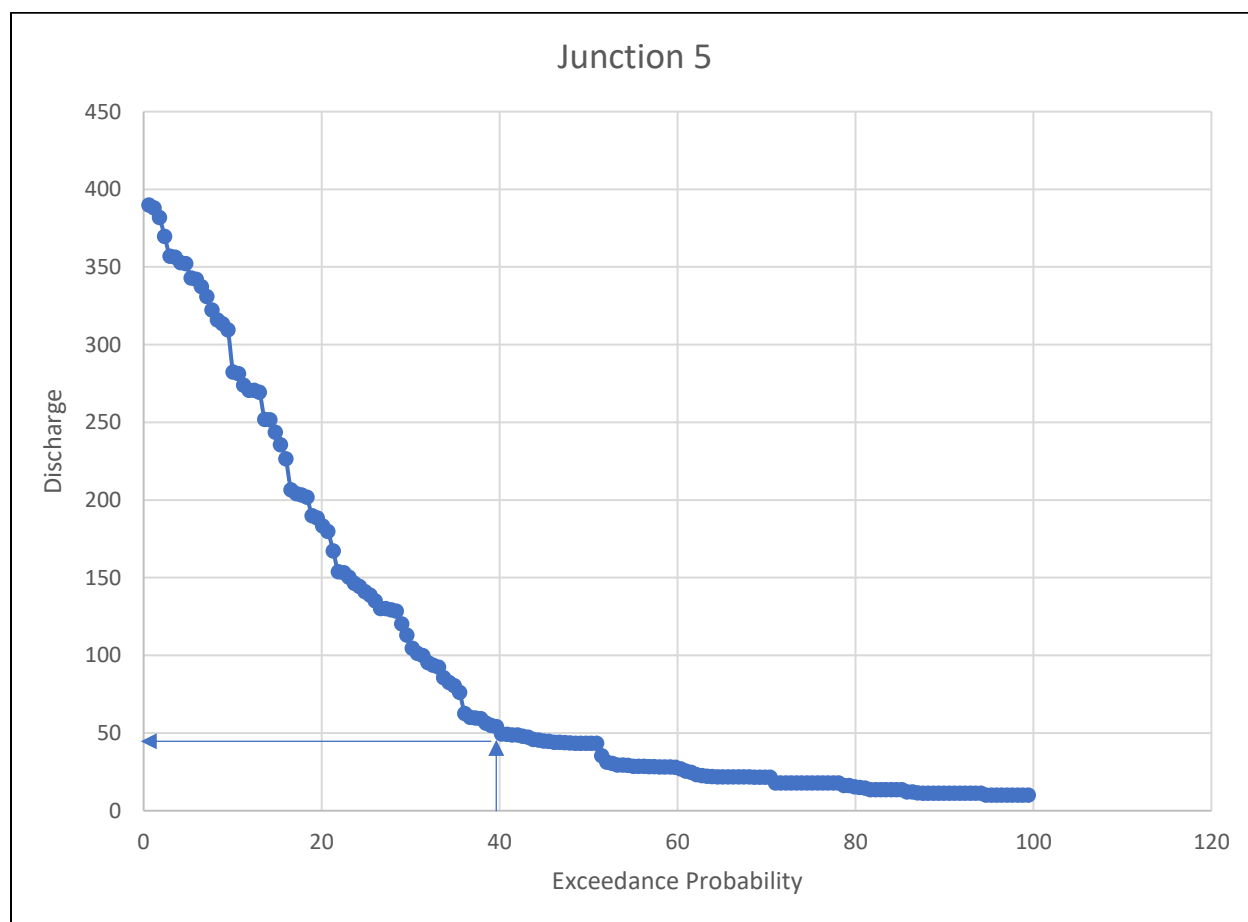
2. Meteorology and Hydrology

Average Annual Precipitation	1760 mm
Catchment Area	411 km ²
Average Flow	26.2 m ³ /s
90% Firm Flow	5.81 m ³ /s
Design (Turbine) Flow	11.30 m ³ /s



SEIA Study of Dudh Koshi -2 (Jaleswor) Hydroelectric Project (70MW)

Feature	70 MW (SEIA, 2019)	230 MW (Approved EIA, 2015)
Minimum operating level (MOL)	779.65 m amsl	775.70 m amsl
Tailrace water level(TWL)	650 m amsl	603 m amsl
Gross head	135 m	182m
Rated head	127.20 m	169.50 m
Design discharge	62.30 m ³ /s	153.44 m ³ /s
Design flood discharge	4,696 m ³ /s (1 in 100 year flood)	

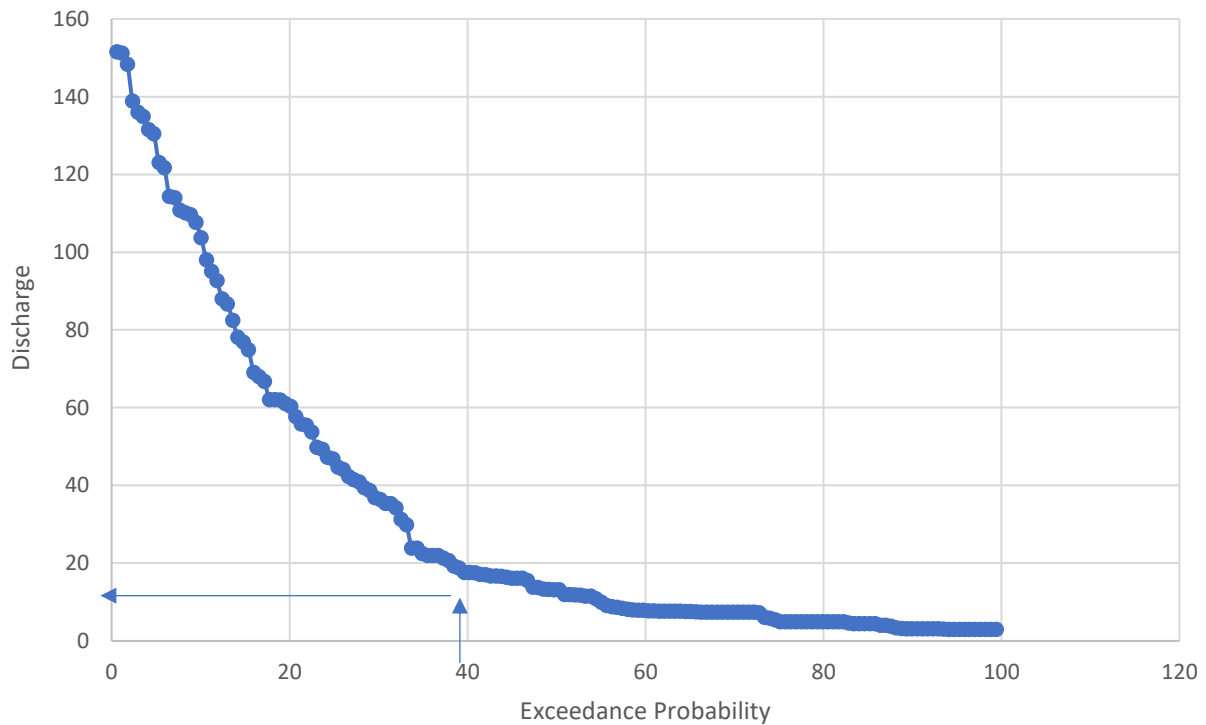


Salient Features

General salient features of the Project are presented below.

River Name	Dudhkoshi Nadi	
Location	Chaurikharka VDC, Solukhumbu District	
Project Area	27° 45' 08" N 27° 41' 56" N 86° 44' 15" E 86° 41' 30" E	North South East West
Intake Location	27° 45' 02" N 86° 42' 55" E	Latitude Longitude
Tailrace Location	27° 41' 59" N 86° 42' 47" E	Latitude Longitude
Weir Crest Elevation	2,650.00 m	amsl
Riverbed Elevation at Tailrace	2,350.00 m	amsl
Weir Height	5.00	m (Approx.)
Tailrace Level above Riverbed for Design Flood	3.00	m (Approx.)
Gross Head (H_{gross})	300.00	m
Maximum Head Loss in Water Conveyance	15	m (5%)
Net Head (H_{net})	285	m
Design Discharge (Q_{design})	49.60	m³/s
Overall Efficiency (η_{total})	80%	
Installed Capacity	111,000	kW
Headrace Length	6	km (Approx.)
Transmission Line Length	10.00	km (Approx.)

Junction 1



Conclusion and Discussions

Design discharge was computed of four hydropower stations with the help of the model NESM3 GCM Model, SSP 245, 2031-44 AD.

Projected Climate Change	Model	SSP	Time Frame	Locations (of HEC-HMS Model)
1) Warm-Dry	NESM3 (China)	2-4.5	2031-44	Junction 1
				Junction 3
				Junction 4
				Junction 5
				Junction 1
			2061-74	Junction 3
				Junction 4
				Junction 5
				Junction 1
				Junction 3
		2086-99	Junction 3	
			Junction 4	
			Junction 5	
			Junction 1	
			Junction 3	
		5-8.5	2031-44	Junction 1
				Junction 3
				Junction 4
				Junction 5
				Junction 1
2061-74	Junction 3			
	Junction 4			
	Junction 5			
	Junction 1			
	Junction 3			
2086-99	Junction 1			
	Junction 3			
	Junction 4			
	Junction 5			
	Junction 1			
2) Warm-Wet	UKESM1-0-LL			
3) Cold-Wet	EC-Earth3-CC (Europe)			
4) Cold-Dry	MPI-ESM1-2-LR (Germany)			

4 Duration Curves discussed prior.

In actual, we will have 24 flow duration curves for each model that means:

A Total of 96 flow duration curves

Figure 12. 96 Flow Duration Curves

Under further investigation and fine tuning of the hydrological model developed from HEC-HMS, projections on 96 different scenarios can be further done that would represent all four projected climate change cases (warm-dry, warm-wet, cold-wet, cold-dry), socio economic pathways (2-4.5 and 5-8.5) in different time frames (2031-2044 AD, 2061-2074 AD, and 2086-2099 AD).

Looking at the results, we can see that the discharge computed is moreover similar to the design discharge of the hydropower. In some cases, the discharge is highly deviated which might be the cause of outliers in the GCM dataset itself. Under solving the problem of outliers in the input datasets, improving the hydrological model and validating the input-procedure-output process to an expert, this study can be made more fruitful and scientific.

Personal Opinion and Feedback towards WECCS-Gen Tool

I really liked using the WECCS-Gen tool because the underlying code behind the tool would automatically give bias corrected spatially disaggregated output. This will really save time and resources of researchers involved in climatic modeling. Despite the convenience of this tool, there are a few minor issues, which if solved, can make this tool more effective:

- If this tool was accessible via Windows
- The output of the WECCS-Gen tool 'BCSD_result.nc' had generic grid and to bring the output to my desired grid, I had to run an extra command: " cdo -setgrid,mygrid BCSD_result.nc mygrid_BCSD_result.nc". Since the WECCS-gen tool already had this information about my datasets, it would be good if this extra step wasn't required.
- Additionally, the WECCS-Gen tool had to be closed and reopened many times due to glitch in the tool in between the change of inputs.
- Sometimes errors were not seen in the WECCS-Gen tool console leading to confusion that there was no error. To see the error, I had to go to the Spyder text editor console.
- It would be great if the WECCSGEN tool provided tools to bias correct the input datasets too (like GPM, ERA5), provided actual on-site data.

Brief Bio

My name is Bibhor Bista. I completed my Bachelor's in Civil Engineering from Institute of Engineering, Thapathali Campus in 2023. I worked as a GIS Intern for Galli Maps for six months where I got to learn the basics of GIS and GIS tools. Currently, I am working as a drone pilot and engineer for Airlift Technology where my major role involves flying drones, generating high-resolution orthomosaics, DEMs and contours. Apart from my professional experience, I have also authored a few research articles. Topics on urban planning, photogrammetry, environmental management, sustainability, disaster risk reduction and management excite me but my major research interest lies in combining remote sensing with water resource analysis to produce insightful and impactful studies that can solve real-world water related problems.