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HBV Rainfall-Runoff Model for Flow Estimation at Ungauged Catchment: A Case Study of Proposed Nupche Likhu Hydropower Project

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Abstract:- Hydroelectric plants are highly dependent on predictable runoff patterns. In the case of Nepal, the specific runoff maps are not available yet and the most of the gauge stations are at low level land. So there is the great challenge of getting reliable hydrological data at intake sites, most of which are at high mountains. The catchment of Nupche and Likhu Intake is far from the gauge station having snow covering and with topographical variations. So, to estimate the flow at Nupche and Likhu intake of proposed Nupche Likhu Hydropower Project Rainfall-Runoff (HBV) Model used. The validated HBV Rainfall-Runoff Model used to estimate the flow of Nupche and Likhu intake of proposed Nupche Likhu Hydropower Project. Only the catchment characteristics of these intake was used as the input of the validate Model. The monthly estimated flow data by the HBV Rainfall-Runoff Model has found similar (Within 10% Variation) with valid monthly flow data. The HBV Rainfall-Runoff Model found applicable to estimate the flow at Nupche and Likhu Intake adjusting catchment variation with the reference of rainfall data of nearest gauged station. The Model can use to estimate the flow of other ungauged catchment after calibration and validation with nearest gauge station

Keywords:- *Hydropower, Ungauged Catchment, Flow Estimation, Nupche and Likhu Khola, Nepal.*

I. INTRODUCTION

Hydroelectric plants are highly dependent on predictable runoff patterns. Increase in river flow, rainfall changes can affect the frequency and intensity of flooding and droughts and have a similar impact on electricity generation. In the case of Nepal, the specific runoff maps are not available yet and the most of the gauge stations are at low level land. So there is the great challenge of getting reliable hydrological data at intake sites, most of which are at high mountains (Shrestha, 2012). Nepal is the developing country, here the Department of Hydrology and Meteorology (DHM) has not been established the gauge station at every catchment area. Most of the catchment on higher elevation is ungauged (Tamrakar & Alfredsen, 2013). Flow pattern is the major factor for governing the capacity of the hydropower plant. Due to topographical or geological variation, the variation occurs on flow pattern. By adjusting the catchment variation, Snowmelt, Snowpack, infiltration, percolation and evaporation Rainfall-Runoff Model is effective for flow estimation at the ungauged area.

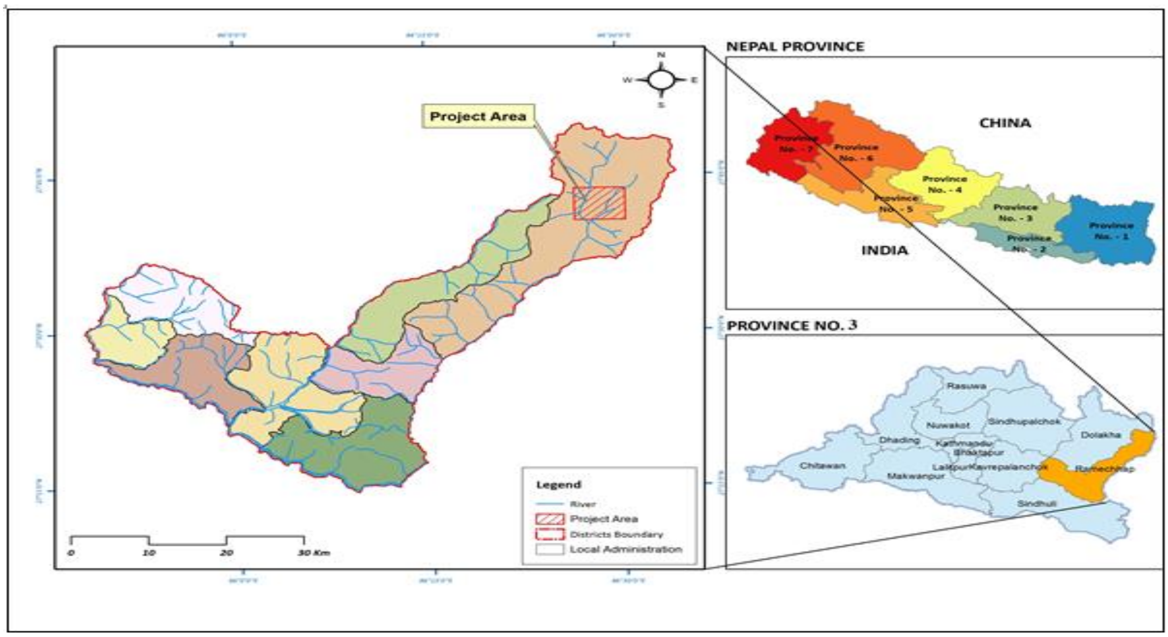

Fig 1:- Study Area (Nupche and Likhu Intake)

Gauge station is far from the project interest point. Simple Basin Area Ratio (BAR) method does not fit to reliably predict the flow of every month as it does not consider the snow area, other topographic variations and groundwater recharge which affects the flow of the stream. So, Rainfall-Runoff Model (HBV) used to estimate the flow at Nupche and Likhu Intake of proposed run-off-river type Nupche Likhu Hydropower Project which considers such topographic variations, snow contribution, rainfall pattern and groundwater contribution for ungauged catchment with the data reference of nearest Sagutar gauge station.

II. HBV RAINFALL RUNOFF MODEL

The Hydrologiska Byråns avdeling for Vattenbalans (HBV) is considered as the standard Rainfall-Runoff Model in Scandinavian countries. The model has been widely used in other countries also. Sten Bergstrom from the Swedish Meteorological and Hydrological Institute (SMHI) developed this model during the early 1970s. The model was first used in Norway in 1974 for runoff forecasting. HBV model is basically a semi-distributed model, meaning that the Precipitation, Temperature and Evaporation as point and catchment are treated as a different zone with consideration in spatial distribution within the catchment.

The major applications of HBV model are:

- Flow estimation at ungauged catchment.
- To generate runoff time series from meteorological data
- Flood forecasting
- To fill in missing runoff data
- Quality control tool for runoff data
- To study the effect of climate change, etc.

The present study mainly concentrates on flow estimation at ungauged catchment with the reference of hydrological and meteorological data from nearest gauge station (Sagutar)

III. MODEL STRUCTURE OF HBV MODEL

Like other Rainfall-Runoff Model, the HBV model is based on the conceptual representation of the few main components in the land phase of the hydrological cycle. Runoff from the catchment is computed from the climatically data like precipitation, air temperature and potential evaporation. The standard version of the HBV model uses the four main storage components: Snow routine, Soil moisture, upper zone (Fast runoff) and Lower zone (Slow runoff). The HBV Rainfall Runoff Model can apply for flow estimation at ungauged catchment after calibration and validation.

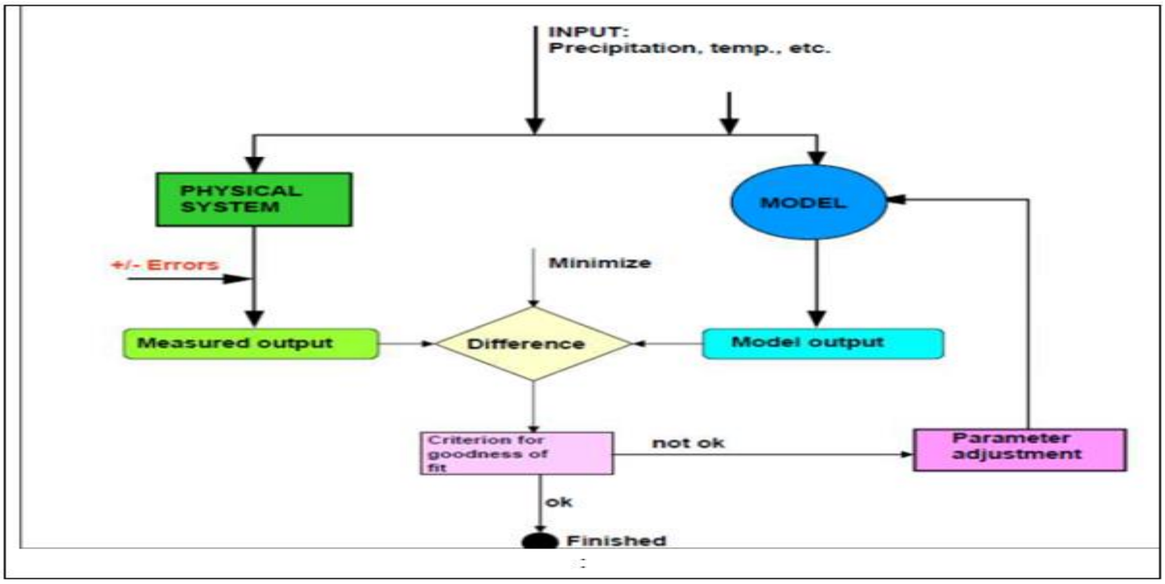

Fig 2:- Structure of HBV Model
Source (Lecture notes: HPD NTNU by professor Anund)

IV. INPUT OF HBV MODEL

Basically the inputs of the HBV Rainfall-Runoff Model are catchment characteristics, precipitation, air temperature, potential evaporation and runoff. The Precipitation, temperature and runoff data was collected from Department of Hydrology and Metrology, Government Nepal, the Catchment data was from Survey Division and potential evaporation by Thornthwaite (1948) formula taking temperature data.

➢ *Precipitation*

Daily precipitation data for Sagutar catchment was taken from average of the five stations. The stations are Jiri station (Index no 1103), Manthali Station (Index no 1123), Chaurikharka Station (Index no 1202), Mane Bhanjyang Station (Index no 1207) and Sirwa Station (index no 1224). The mean data is as per Thiessen weight 0.12, 0.03, 0.15, 0.21 and 0.49 respectively. The precipitation data was from 1987 to 2016.

➢ *Temperature*

The daily temperature data was taken from Jiri station. The temperature data from 1987 to 2016 was taken as input. The available data was checked and analyzed by using comparison method of the individual year and mean monthly variation.

The available data has analyzed for seasonal and monthly variation.

➢ *Runoff*

The hydrology of the Nepalese river has closely flowed the rainfall pattern. The flow in the river is high during the month of June to September followed by a period of recession from the month of October to December.. Runoff data from 1987 to 2016 was taken as input.

➢ *Potential Evaporation*

The Thornthwaite (1948) formula is based mainly on temperature with an adjustment being made for the number of daylight hours as input. An estimate of Potential Evaporation (PE) calculated on a monthly basis is given by (Timilsina, 2008):

$$PE_m = 16\, N_m \{10T_m/I\}^a, \text{mm}$$

Where m is the months 1, 2, 3….12, Nm is the monthly adjustment factor related to hours of daylight, Tm is the monthly mean temperature ºC, I is the heat index for the year, given by:

$$I = \Sigma\, (T_m/5)^{1.5} \text{ for } m = 1, 2 \ldots 12$$

And

$$a = 6.7 \times 10^{-7} I^3 - 7.7 \times 10^{-5} I^2 - 1.8 \times 10^{-2} I + 0.49$$

➢ *Catchment Characteristics*

The Catchment data of Sagutar, Nupche Intake and Likhu Intake catchment was taken by Arc GIS tool using the land cover data from Survey Division. Catchment data of Sagutar used for calibration and validation of the Model. Catchment data of Nupche and Likhu Intake was used for flow estimation.

V. HBV MODEL CALIBRATION

The Model was calibrated for Sagutar catchment by using the precipitation, air temperature, potential evaporation and discharge data from 1987 to 2001 and catchment data of Sagutar catchment The set of the parameters was chosen as Table-1 by heat and trial method with best possible correspondence between the simulated and observed runoff for Sagutar catchment.

Symbol	Meaning	Name	Value Range from Norway Basin	Calibrated value of Sagutar Basin	Units
PREC	Rain - correction:	PKORR	1.05 to 1.20	1.45	
	Snow - correction:	SKORR	1.15 to 1.50	1.2	
	Elevation corr:	HPKORR	1.0 to 1.10	1.1	% pr. 100 m
SNOW	Degree-day factor:	CX	3.0 to 6.0	3	mm/degree C./day
	Threshold snow-melt:	TS	-1.0 to 2.0	2	Degree C.
	Threshold Rain/Snow:	TX	-1.0 to 2.0	-1	Degree C.
	Liquid water:	CPRO	5.0 to 16	15	% of dry snow
SOIL	Field capacity:	FC	75 to 300	80	mm
	BETA:	BETA	1 to 4	2.5	
	Threshold evaporation:	LP	55 to 300	70	mm
UPPER	Fast drainage coeff:	KUZ2	0.1 to 0.5	0.2	1/day
	Slow drainage coeff:	KUZ1	0.05 to 0.15	0.07	1/day
	Threshold:	UZ1	10 to 40	35	mm
	Percolation:	PERC	0.5 to 1	0.8	mm/day
LOWER	Drainage coeff:	KLZ	0.002 to 0.005	0.004	1/day
REFREEZE		PRO	0 to 10	10	% of normal melt rate
	Temperature lapse rate:				
	At precipitation........			-0.62	Degree C./100m
	No precipitation........			-1.1	Degree C./100m

Table 1:- Optimized Parameter details of Sagutar Basin

The applicable Efficiency (R^2) value of HBV Rainfall-Runoff Model calibration range 0.6 to 0.90, as shown in table-2. The average R^2 value for Model calibration of Sagutar basin (1987 to 2001) is 0.772 as on Table-2.

Years	R^2	Remarks
1987	0.764	
1988	0.849	
1989	0.835	
1990	0.730	
1991	0.737	
1992	0.755	
1993	0.787	
1994	0.820	
1995	0.612	
1996	0.748	
1997	0.769	
1998	0.773	
1999	0.798	
2000	0.790	
2001	0.808	
Avg	**0.772**	

Table 2:- Table for the R^2 value of the calibration

S.N.	Month	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)	Deviation	Remarks
1	January	15.235	16.790	-10%	
2	February	11.977	13.420	-12%	
3	March	11.397	11.159	2%	
4	April	12.363	11.244	9%	
5	May	20.553	16.994	17%	
6	June	61.308	54.637	11%	
7	July	156.103	141.232	10%	
8	August	182.129	165.430	9%	
9	September	112.004	112.617	-1%	
10	October	52.840	54.881	-4%	
11	November	29.782	33.939	-14%	
12	December	22.973	25.558	-11%	

Table 3:- Table for comparison of observed and simulated discharge

The monthly deviation of observed discharge data and the simulated discharge data from 1987 to 2001 is -1% to 17%, deviation is below 20% as presented on Table-3. The efficiency (R^2) and monthly deviation value indicated that the set of parameters by heat and trial as shown has the best value of efficiency criterion. The validation can proceed with the precipitation, temperature, evaporation data of next years and set of parameters with the calibrated value.

VI. HBV MODEL VALIDATION

Validation of the model should be done to examine the practicability for the estimation of the flow and other proposed. Before using the HBV Rainfall-Runoff Model to estimate the flow at ungauged catchment Nupche and Likhu Intake Calibrated model has been tested by fixing the set of the parameters and inputting the independent precipitation, air temperature, potential evaporation and discharge data from 2002 to 2016. The catchment data of Sagutar basin was used for the validation of the model.

The efficiency (R^2) value range of the HBV Rainfall-Runoff Model is 0.6 to 0.9. The calibrated model by using the inputs of 1987 to 2001 was verified by fixing the set of the calibrated parameters and inputs of different years. The average efficiency (R^2) value is 0.753 as presented on Table-4.

Years	R^2	Remarks
2002	0.754	
2003	0.842	
2004	0.686	
2005	0.729	
2006	0.613	
2007	0.789	
2008	0.734	
2009	0.814	
2010	0.842	
2011	0.748	
2012	0.729	
2013	0.738	
2014	0.699	
2015	0.812	
2016	0.774	
AVG	**0.753**	

Table 4:- Table for R^2 value of validation

S.N.	Month	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)	Deviation	Remarks
1	January	14.489	16.412	-13%	
2	February	12.179	13.544	-11%	
3	March	11.330	11.024	3%	
4	April	11.758	10.447	11%	
5	May	18.294	15.639	15%	
6	June	47.296	44.143	7%	
7	July	143.164	138.123	4%	
8	August	156.358	153.893	2%	
9	September	101.815	103.956	-2%	
10	October	57.424	60.555	-5%	
11	November	30.907	35.568	-15%	
12	December	21.345	23.422	-10%	

Table 5:- Table for comparison of observed and simulated discharge

The monthly deviation between the observed and simulated discharge data from 2002 to 2016 is -2% to -11%, deviation is below 20% as presented on Table-5. As per the average efficiency (R^2) value and the monthly deviation value between observed and simulated discharge the Model has been evaluated within confident range for flow estimation at ungauged catchment Nupche and Likhu Intake of the proposed Nupche Likhu Hydropower project.

VII. MONTHLY FLOW OF NUPCHE INTAKE

The flow has been estimated at ungauged catchment, Nupche Intake of proposed Nupche Likhu Hydropower Project by application of the HBV Rainfall-Runoff Model. Using the catchment characteristics of Nupche intake as input and keeping other input of the validate Model constant the flow was estimated by HBV Rainfall-Runoff Model. Flow has been estimated by Basin Area Ratio method with the discharge of the Sagutar basin.

S.N.	Month	Flow Estimated By HBV Model (m³/s)	Flow Estimated by BAR with Sagutar (m³/s)	Valid flow at Nupche Intake(m³/s)	Variation of Flow by HBV with valid flow	Variation of Flow by BAR with valid flow
1	January	2.17	1.47	2.07	-5%	40.82%
2	February	1.9	1.25	1.85	-3%	48.00%
3	March	1.873	1.18	1.826	-3%	54.75%
4	April	2.225	1.29	2.059	-7%	59.61%
5	May	3.268	1.87	3.134	-4%	67.59%
6	Jun	8.496	4.9	8.073	-5%	64.76%
7	July	20.351	13.67	19.619	-4%	43.52%
8	August	22.53	15.42	22.078	-2%	43.18%
9	September	17.398	11.06	16.453	-5%	48.76%
10	October	9.318	5.81	8.559	-8%	47.31%
11	November	4.986	3.05	4.669	-6%	53.08%
12	December	3.213	2.02	2.983	-7%	47.67%

Table 6:- Monthly flow at Nupche Intake
Valid flow, Source: VEPL, 2018)

As per the result outcomes presented on Table-6, the monthly flow of Nupche intake by Basin Area Ratio method is far difference with valid flow. The variation of monthly flow estimated HBV Rainfall-Runoff Model is within 10% with valid flow. The catchment of Nupche Intake has topographical variation with snowpack and snowmelt. Basin Area Ratio Method does not estimate the flow by adjusting the topographical variation. Hence, the HBV Rainfall-Runoff Model is applicable for flow estimation by adjusting topographical variation, snowmelt and snowpack.

VIII. MONTHLY FLOW OF LIKHU INTAKE

The flow has been estimated at ungauged catchment, Likhu intake of proposed Nupche Likhu Hydropower Project by application of the HBV Rainfall-Runoff Model. Using the catchment characteristics of Likhu intake as input and keeping the inputs of validate Model constant the flow has been estimated by HBV Rainfall-Runoff Model. The discharge data has been estimated by Basin Area ratio method with the discharge of the Sagutar basin. The monthly flow estimated by BAR and HBV Model have been detailed on Table 7.

S.N.	Month	Flow Estimated By HBV Model (m³/s)	Flow Estimated by BAR with Sagutar (m³/s)	Valid flow at Likhu Intake(m³/s)	Variation of Flow by HBV with valid flow	Variation of Flow by BAR with valid flow
1	January	1.87	1.22	1.8	-4%	47.54%
2	February	1.67	1.04	1.537	-8%	47.79%
3	March	1.67	0.98	1.515	-9%	54.59%
4	April	1.86	1.07	1.707	-8%	59.53%
5	May	2.78	1.55	2.599	-7%	67.68%
6	Jun	7.00	4.07	6.699	-4%	64.59%
7	July	17.76	11.33	16.265	-8%	43.56%
8	August	19.01	12.79	18.31	-4%	43.16%
9	September	14.09	9.17	13.643	-3%	48.78%
10	October	7.59	4.82	7.099	-7%	47.28%
11	November	4.21	2.53	3.872	-8%	53.04%
12	December	2.59	1.68	2.476	-5%	47.38%

Table 7:- Monthly Flow at Likhu Intake
(Valid flow, Source: VEPL, 2018)

As per the result outcomes presented on Table-7, the monthly flow of Likhu Intake by Basin Area Ratio method is far difference with valid flow. The variation of monthly flow estimated HBV Rainfall-Runoff Model is within 10% with valid flow. The catchment of Likhu Intake has topographical variation with snowpack and snowmelt. Basin Area Ratio Method does not estimate the flow by adjusting the topographical variation. Hence, the HBV Rainfall-Runoff Model is applicable for flow estimation by adjusting topographical variation, snowmelt and snowpack.

IX. DISCUSSION AND CONCLUSION

Nupche and Likhu catchment has been taken in the study of Hydrological modeling, where the Nupche Likhu Hydropower project is planned. Besides, the catchment has a unique characteristic where there is altitude variation from elevation 3338 masl to 6171 masl.

The data were collected from different resources and the quality of data (precipitation, discharge, temperature, Evaporation) has been checked by different methods to their consistency.

The weighting in the five precipitation station Jiri, Manthali, Chaurikharka, Mane Bhanjyang and Sirwa is calculated by the Thiessen Polygon Method. The weight age given to three stations is 0.12, 0.03, 0.15, 0.21 and 0.49 respectively.

HBV model is well set up in the study catchment and free parameters in the gauge catchment have been found by heat and trial method in the simulation process. The calibration period of the model is finalized from 1987 to 2001 and the validation period is from 2002 to 2016. The average R^2 value is found 0.772 in the case of calibration and 0.753 in the case validation in gauge catchment. The R^2 value ranges from 0.612 to 0.849 in most of the years of calibration.

The validated Model has been used to estimate the flow at Nupche and Likhu Intake (Ungauged catchment) of proposed Nuche Likhu Hydropower Project. The Monthly estimated data by the Model is similar (Within 10% Variation) with valid monthly flow. The HBV Rainfall-Runoff Model has been found applicable to estimate the flow at Nupche and Likhu Intake adjusting catchment variation.

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