

Appraisal of Hydropower Potential of Nepal

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* Founders of **Geomorphological Society of Nepal (GSN)**

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Nepal Engineer's Association Talk Program

Personal backgrounds

- **Dr. Krishna Prasad Dulal** - PhD in River Morphology - Hokkaido University, Japan (2009). Worked in the water resources and energy sector for over 20 years in various capacities with different organizations. Currently -Managing Director at DK Consult Pvt. Ltd. Has served as Board Director for Nepal Electricity Authority (15 months). Founding member of Geomorphological Society of Nepal (GSN)

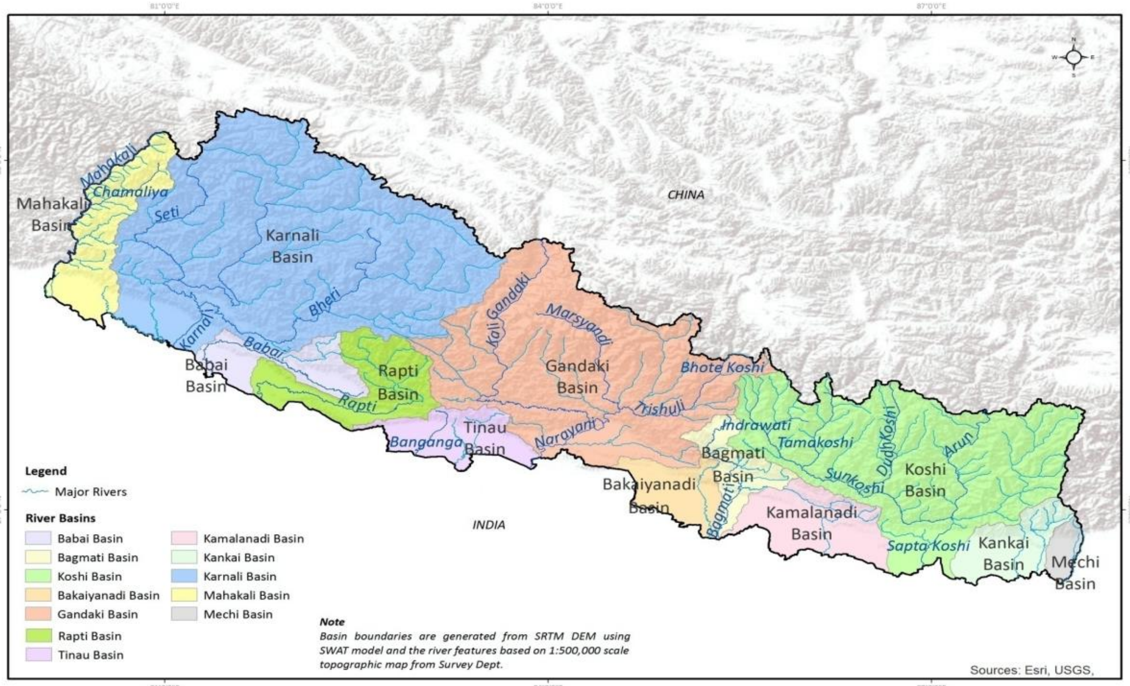
- **Dr. Nagendra Kayastha** - PhD in Hydroinformatics (Hydrology and Water Management) - Delft University of Technology, the Netherlands (2014). More than 20 years of national and international experiences in river flood and water resource management studies including hydropower and consulting projects in Nepal. Currently - Independent Researcher in the Netherlands. Founding member (GSN).

- **Dr. Umesh Singh** - joint Doctoral degree in River Science at University of Trento and Queen Mary University (2015). More than 10 years of national and international experiences in river engineer including hydropower. Currently - Senior Research Engineer at Hydro lab Pvt Ltd, Nepal. Founding member of GSN.

Outline of the presentation

- Introduction
- Key results
- Methodology
  - Systematic framework
  - Gross Hydropower Potential
  - SWAT hydrological modelling
  - Project Spotting
  - Cost Analysis
  - Cost and Benefit Analysis
  - Multi-Criteria Analysis
- Techno-economically feasible HP projects

Introduction (1)



- Annual Runoff 200 billion cumec draining north to south *(12 River Basins)*
- High head: North-South Elevation difference > 8000 m in a stretch of 200 km
- Data collection & advances in hydro-metrological & geo-spatial modelling tools in past 50 yrs
- Infrastructure development and economic growth observed in past 50 years
- Reassessment of Hydropower Potential of Nepal required

Introduction (2)

- Gross Hydropower potential of Nepal: 83000 MW is based on the PhD dissertation of Dr. Hariman Shrestha (1963-1966).
- His work was not accessible, reviewed from other authors citing his research: mainly (Bajracharya, 2015) and Jha (2010)
- Bajracharya has attempted to provide more details of Shrestha's work
- Information on citing researches have been observed inconsistent:

"According to him, each drop of water was used to calculate the power potential and the considered **efficiency was 100%**" Jha, 2010

"Using the head and average zonal discharge, the power was calculated for both major rivers and small rivers using **80% system efficiency**" Bajracharya, 2015

- Even Shrestha (2015) provides very few details of his 1966 work
- Gross Hydropower Potential of Nepal: 200,000 MW (Pradhan, 2008), does not provide basis of calculation at all

Introduction (3)

- Technical Hydropower potential of Nepal: 43,422 MW is also based on Shrestha's 1968 work with updates in 1995.

"As per this report such projects numbered 122, of which 23 projects were covered at that time at least to prefeasibility level study. ***The technical potential of all these 122 projects added together gives 43,442 MW*** *in terms of installed capacity" Shrestha (2015)*

- Prachar Man Singh Pradhan (2009) quotes different figures citing to WECS:

Table 5.2 Technical Hydropower Potential

River Basin	Number of Project Sites	Technical Potential/ Capacity in MW
Sapta Kosi	53	11,400
Sapta Gandaki	18	6,660
Karnali	30	25,410
Mahakali	4	1,160
Southern rivers	9	980
Country Total	114	45,610

Table 5.3 Economical Hydropower Potential

River Basin	Number of Project Sites	Economic Potential/ Capacity in MW
Sapta Kosi	40	10,860
Sapta Gandaki	12	5,270
Karnali	7	24,000
Mahakali	2	1,125
Southern rivers	5	878
Country Total	66	42,133

Source: Water and Energy Commission (WEC), Kathmandu

- Technical Potential: 45,610 MW
- Economic Potential: 42,133 MW

- Both Shrestha's and WECS work were not accessible for review

Introduction(4)

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Hydropower Potential Estimations and Small Hydropower Plants Siting: Analysis of World Experience

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- Definition adopted in international practices:

"Gross hydropower potential is the maximum theoretically possible amount of energy stored in the stream"

"Available hydropower potential is the part of the gross potential after deductions due to ecological, economical or other restrictions" (Deducting sites that are already developed for other uses)

"Technical potential is the part of the available potential, which can be developed based on present construction technologies and experience in hydropower development"

"Economical potential is the economically feasible part of the technical potential" (can also be referred as techno-economical potential)

Introduction (5) = Environment release

	Discharge	Head	Efficiency	Technical comp	Economical comp
Gross HPP		Gross	✗	✗	✗
Technical HPP		Net	✓	✓	✗
Economical HPP		Net	✓	✓	✓

Boundary Limitations

- Area below 5000m elevation and above the Chure foothill is considered for the potential estimations.
- Catchment area above 10 km2 is for stream generation
- River discharge above 0.10 m3/s and elevation difference of 25m is considered for Power generation
- Project above 500 kW is considered in this study

Key Results (1): Gross (RoR) Hydropower Potential

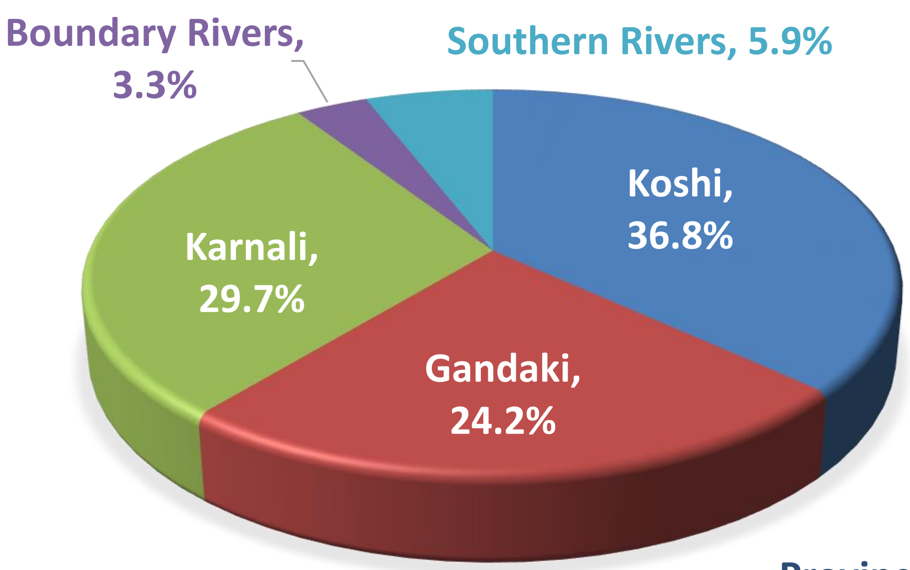
- **3712 reaches analyzed**

River Basins	Number of river reaches
Koshi	650
Gandaki	1361
Karnali	1248
Kankai	46
Kamala	62
Bagmati	50
Bakaiya	35
Tinau	20
Rapti	55
Babai	51
Mechi	12
Mahakali	122
Total	3712

SN	River basin	Adopted
1	Koshi	24012
2	Gandaki	15788
3	Karnali	19389
4	Rapti	2314
5	Bagmati	563
6	Babai	195
7	Kankai	328
8	Kamala	261
9	Tinau	112
10	Bakaiya	84
11	Mechi	62
12	Mahakali	2120
	Total	**65,228**

65,228 MW

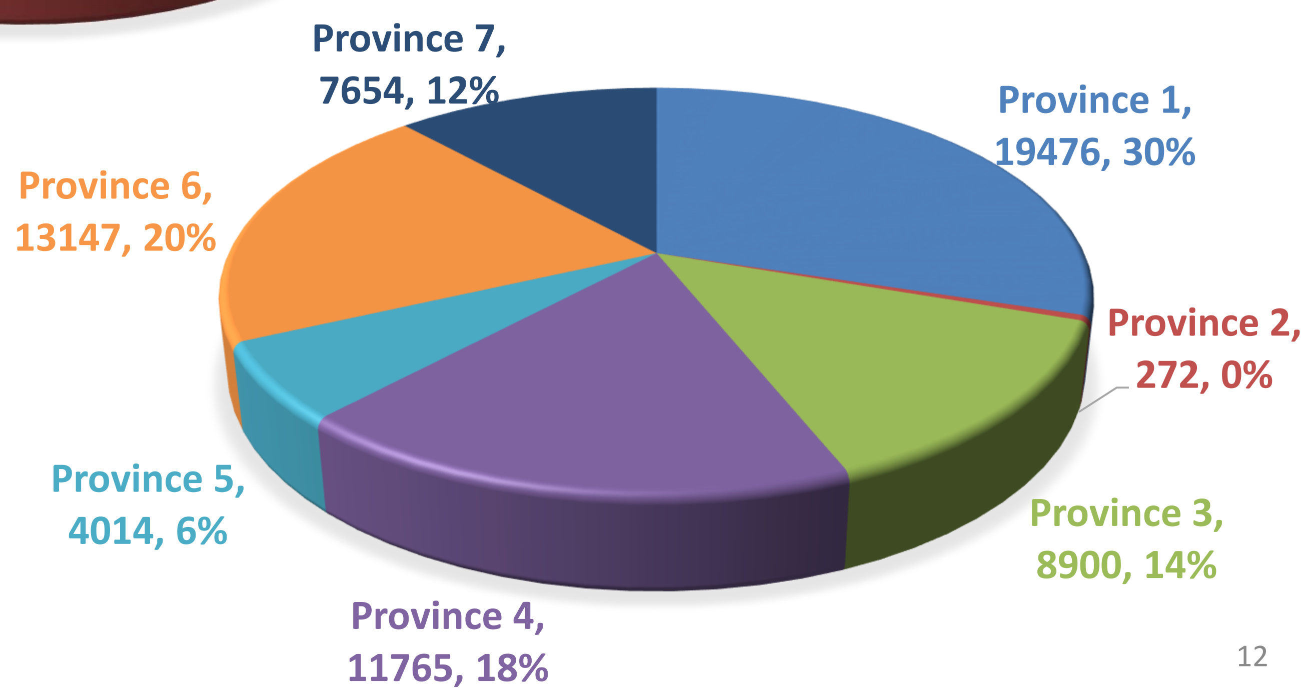
Key Results (2): Gross (RoR) Hydropower Potential



Basins	%
Koshi	36.8
Gandaki	24.2
Karnali	29.7
S. Rivers	5.9
B. Rivers	3.3

65,228 MW

Provinces	%
1	30
2	0
3	14
4	18
5	6
6	20
7	12



Key Results (3): Gross (RoR) Hydropower Potential

Koshi basin

Tributaries	Power Potential (MW)	% of basin potential
Arun	4665	19.4
Tamor	**6937**	**28.9**
Dudhkoshi	3443	14.3
Tamakoshi	1519	6.3
Bhotekoshi	1104	4.6
Sunkoshi	5694	23.7
Saptakoshi	651	2.7
Total	**24012**	**100**

Karnali basin

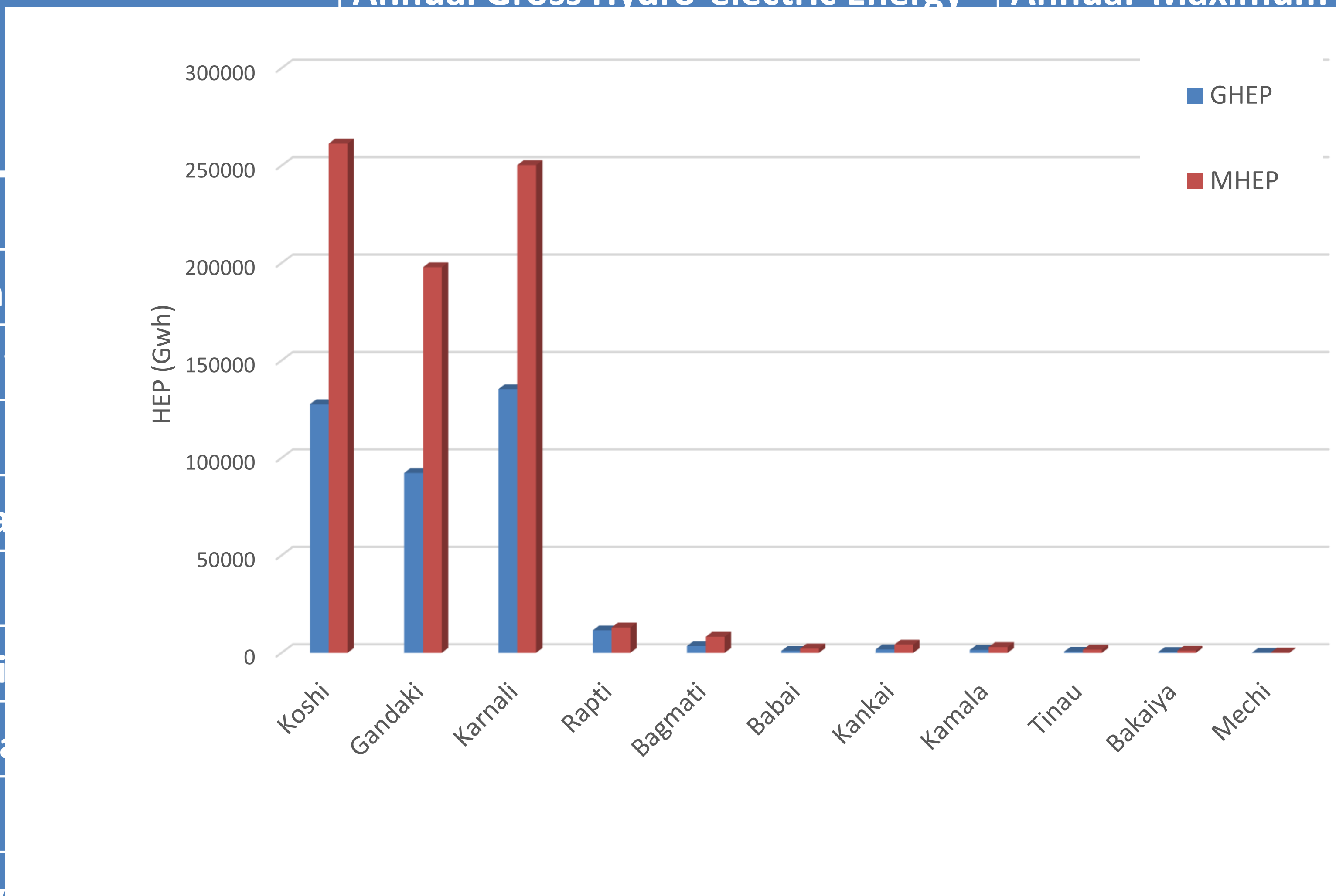
Tributaries	Power Potential (MW)	% of basin potential
West Seti	3360	17.3
Upper Karnali	**8491**	**43.8**
Bheri	5996	30.9
Southern part	1543	8.0
Total	**19389**	**100**

Gandaki basin

Tributaries	Power Potential (MW)	% of basin potential
Kaligandaki	5007	31.7
Trishuli	**8414**	**53.3**
Seti Narayani	2366	15.0
Total	**15788**	**100**

Key Results (4): Gross Hydroelectric Potential (GHEP)

Basins	Annual Gross Hydro-electric Energy	Annual Maximum Hydro- tential
Koshi		
Ganda		
Karnali		
Rapti		
Bagma		
Babai		
Kankai		
Kamala		
Tinau		
Bakaiya		
Mechi	99	1,60



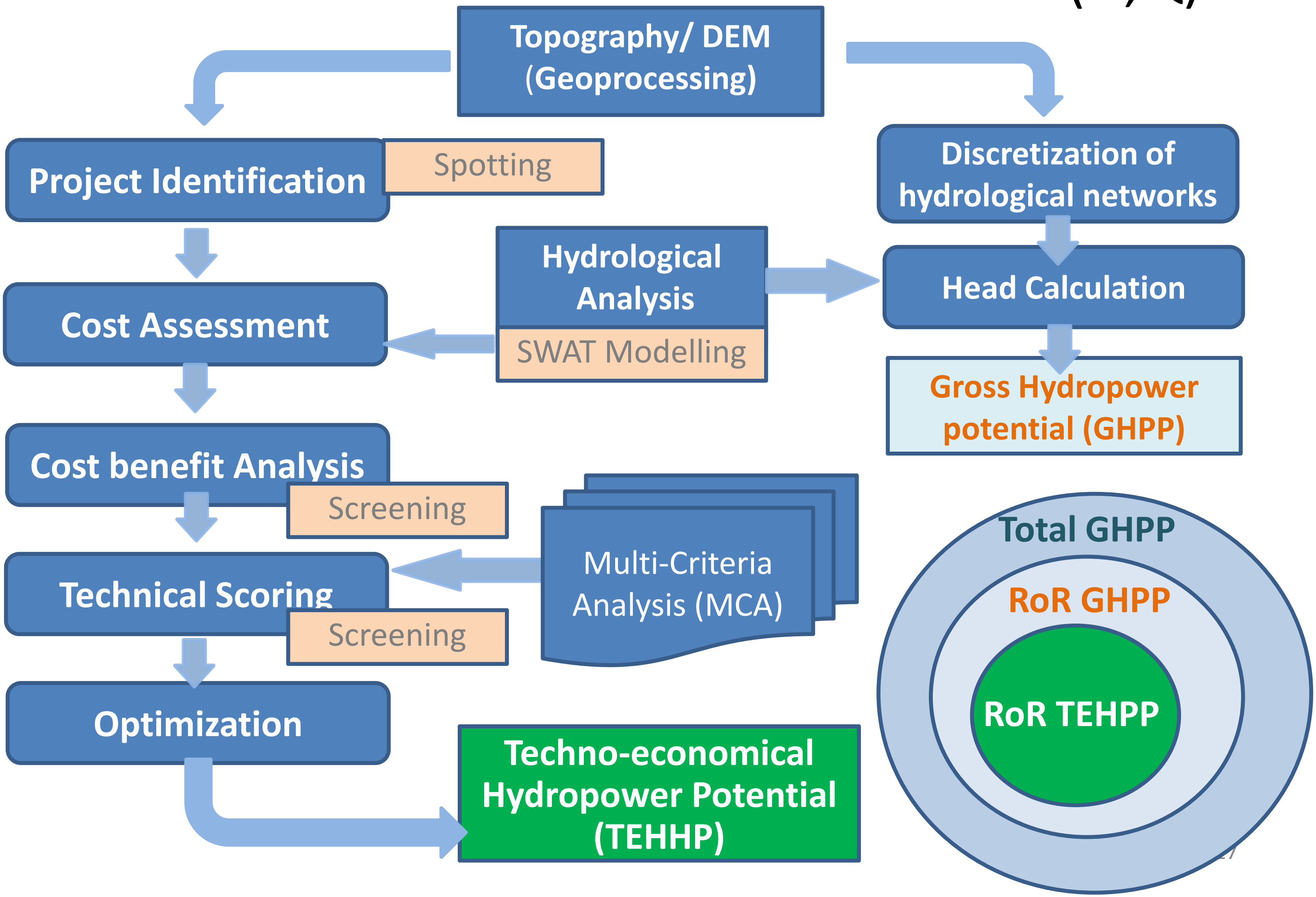
Key Results (5): Comparison with literature

	Q_{40}	Q_{mean}	Q_{40}	Q_{40}	Q_{mean}
Basins	**This study**	**Shrestha [1966]**	**Jha [2010]**	**Prajapati [2015]**	**Bajracharya [2015]**
Koshi	24,012	22,350	21,260		35,166
Gandaki	15,788	20,650	22,250		32,086
Karnali	19,389	32,010	19,576	23,109	25,755
Other basins	6,039	8,171	4,209		10,334
Total (MW)	65,228	83,181	67,295	--	103,341
Efficiency	**100%**	**100%/ 80%**	**80%**	**80%**	**100%**

Appraisal of
Hydropower Potential of Nepal
Methodology

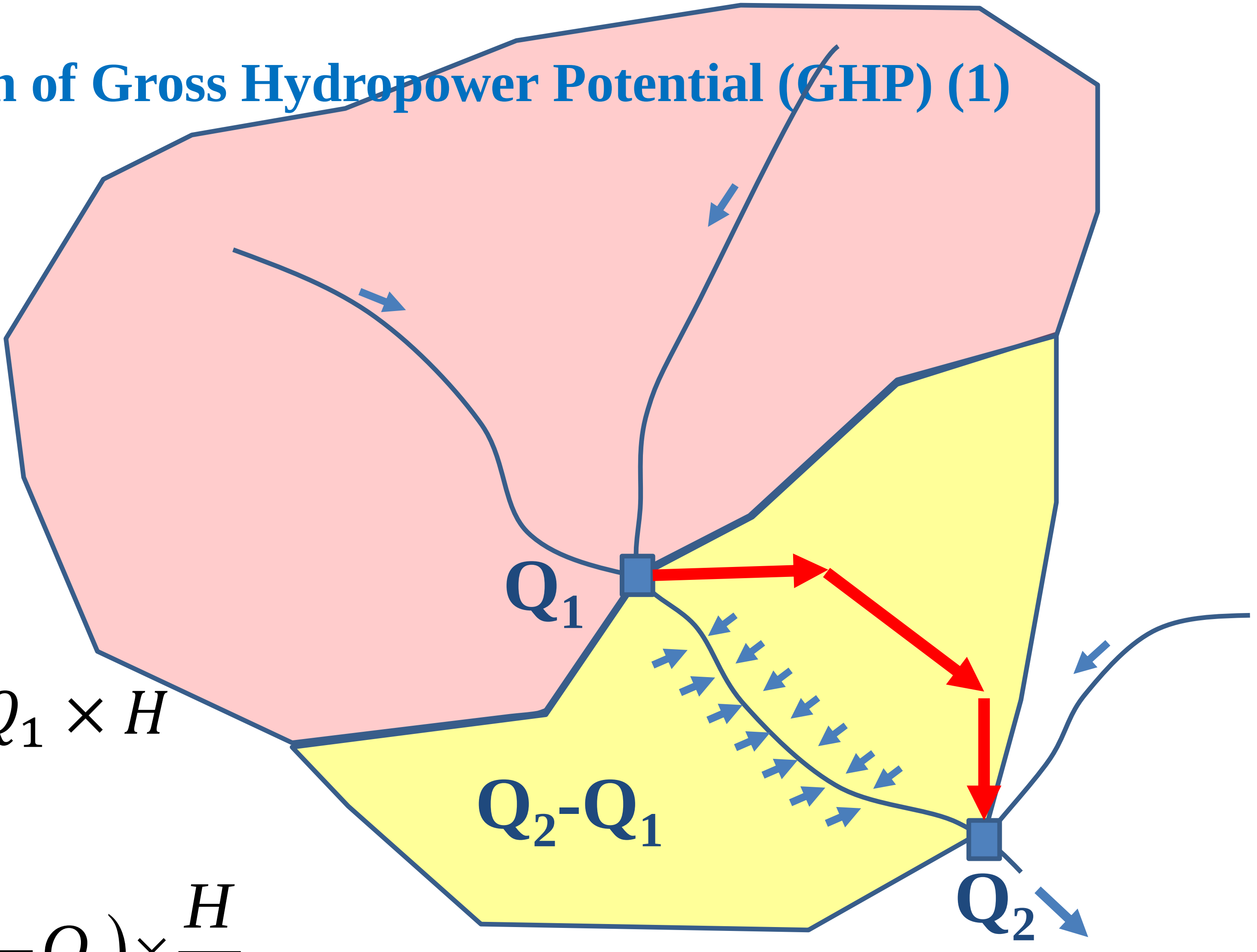
Systematic framework (ROR)

$$HPP = F(H,Q)$$



Computation of Gross Hydropower Potential (GHP) (1)

Hall et al (2004)



Component-1

$$P_1 = 9.81 \times Q_1 \times H$$

Component-2

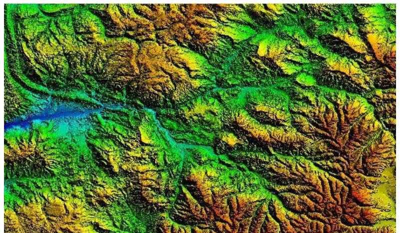
$$P_2 = 9.81 \times (Q_2 - Q_1) \times \frac{H}{2}$$

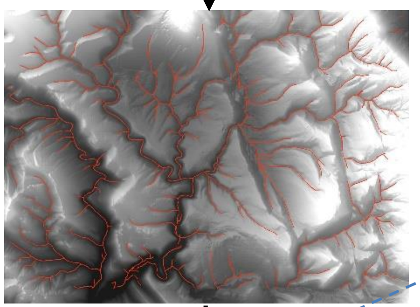
$$P = P_1 + P_2$$

$$P = 9.81 \times \left(\frac{Q_1 + Q_2}{2} \right) \times H$$

Computation of Gross Hydropower Potential (GHP) (2)

Terrain data

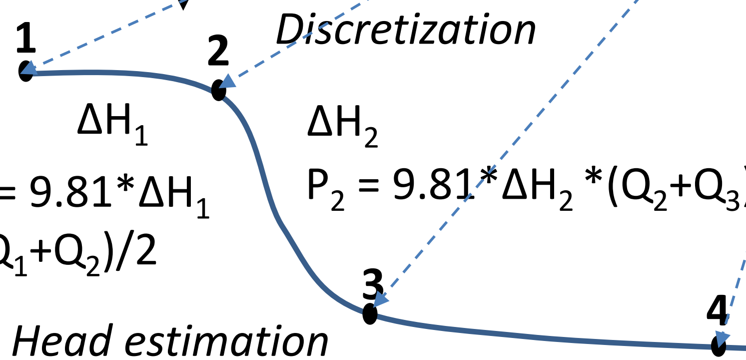




Drainage network

GIS Analysis

- *Discretization*
- *Head estimation*



Discretization

ΔH_1

$P_1 = 9.81 * \Delta H_1 * (Q_1+Q_2)/2$

ΔH_2

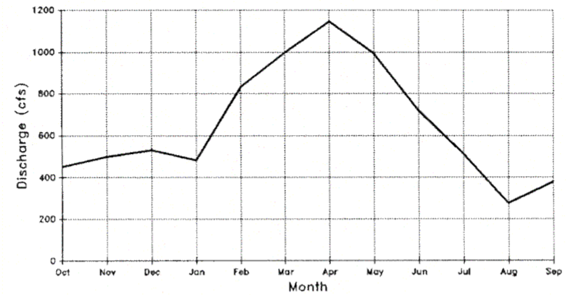
$P_2 = 9.81 * \Delta H_2 * (Q_2+Q_3)/2$

Head estimation

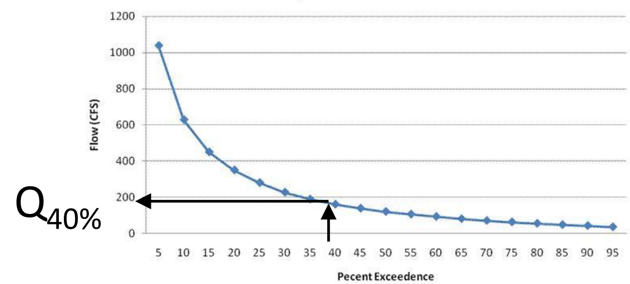
ΔH_3

$P_3 = 9.81 * \Delta H_3 * (Q_3+Q_4)/2$

Annual Flow



Flow duration curve



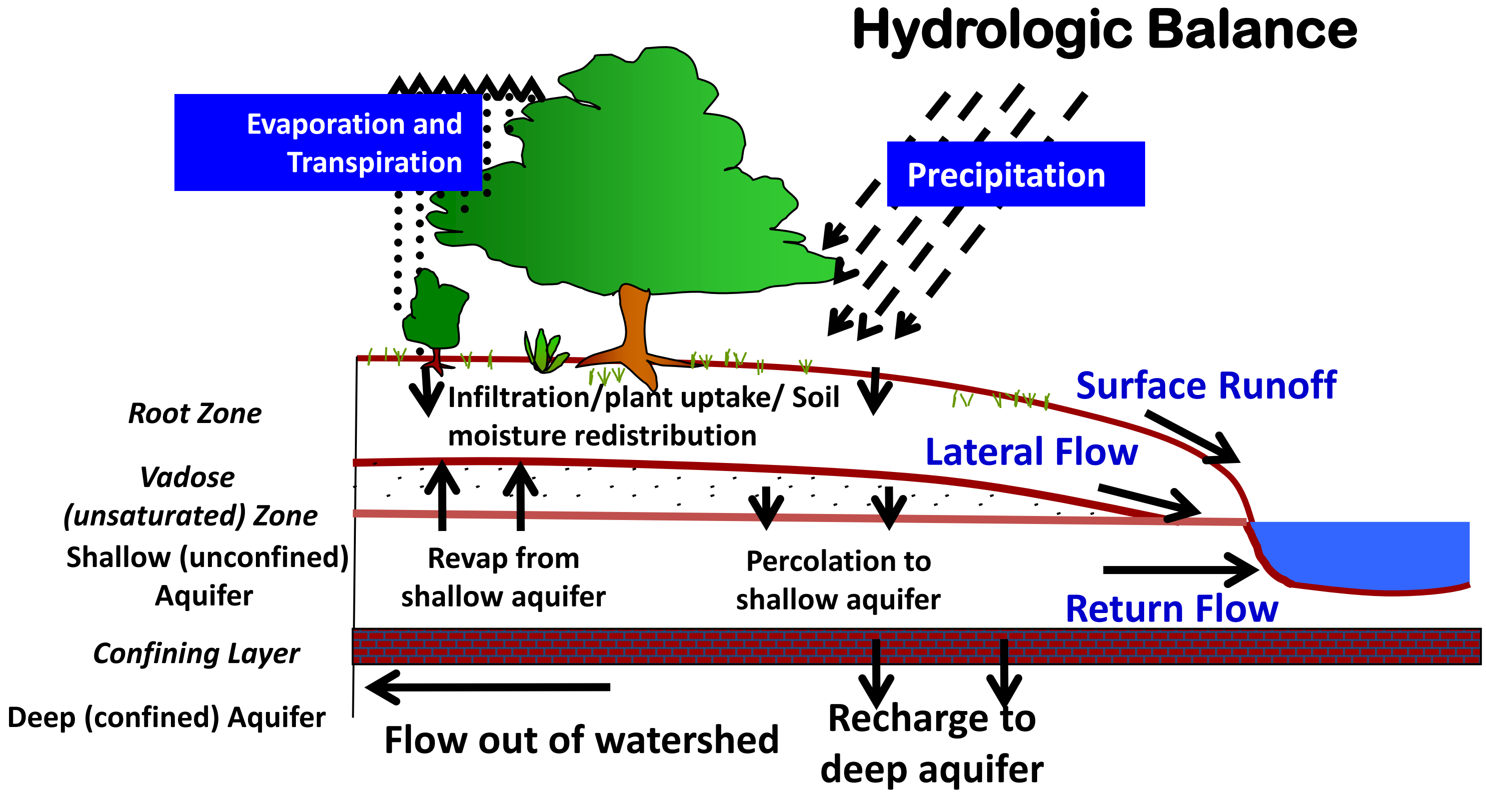
Hydrological Analysis

$$GHPP = \sum_{i=1}^{i=n} P_i$$

Power Computation

Hydrological Analysis : SWAT modelling (1)

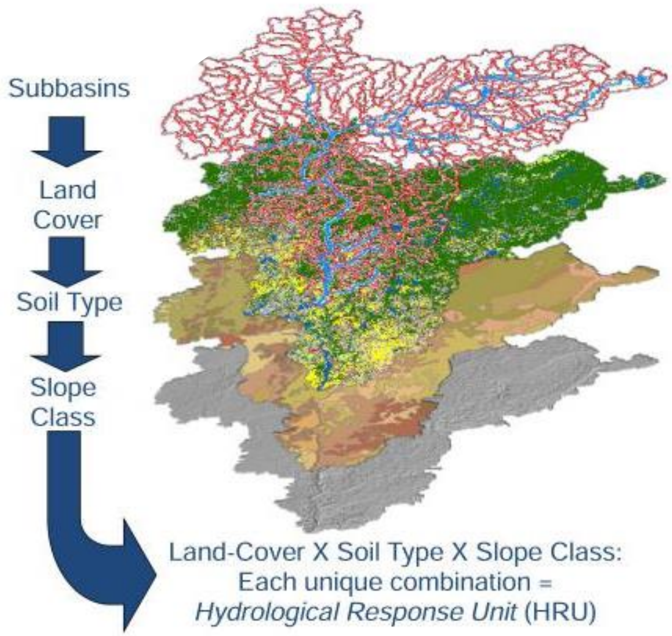
SWAT Soil & Water Assessment Tool



Schematic of hydrologic processes simulated in SWAT (Arnold et al. 1998)

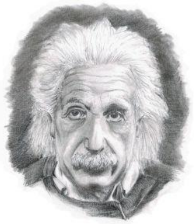
Hydrological Analysis : SWAT modelling (2)

- Simulation of processes at land and water phase
- Spatially distributed (different scales)
- Semi physically based approaches
- Simulation of changes (**climate, land use**, management etc.)
- Water quantities, incl. different runoff components
- Water quality: Nutrients, **Sediments**, Pesticides, Bacteria, (algae and oxygen), etc.



Semi-distributed modelling approach

SWAT estimates discharge at required reach in the basin



More Physics Based !!

Hydrological Analysis : SWAT modelling (3)

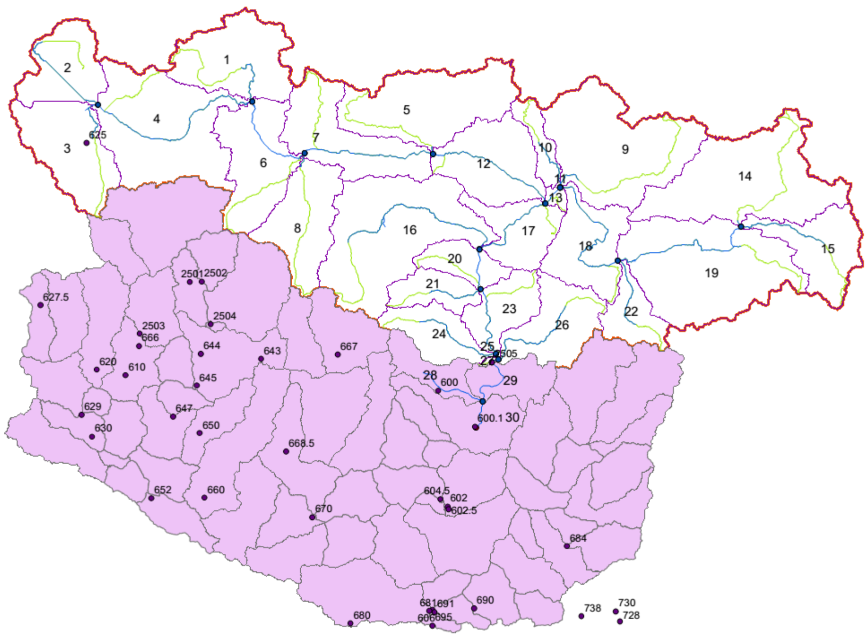
Big River basins	Small River basins
Koshi	Mahakali
Narayani	Babai
Karnali	West Rapti
	Tinau
	East Rapti
	Bagmati
	Kankai

River basins modelled in SWAT

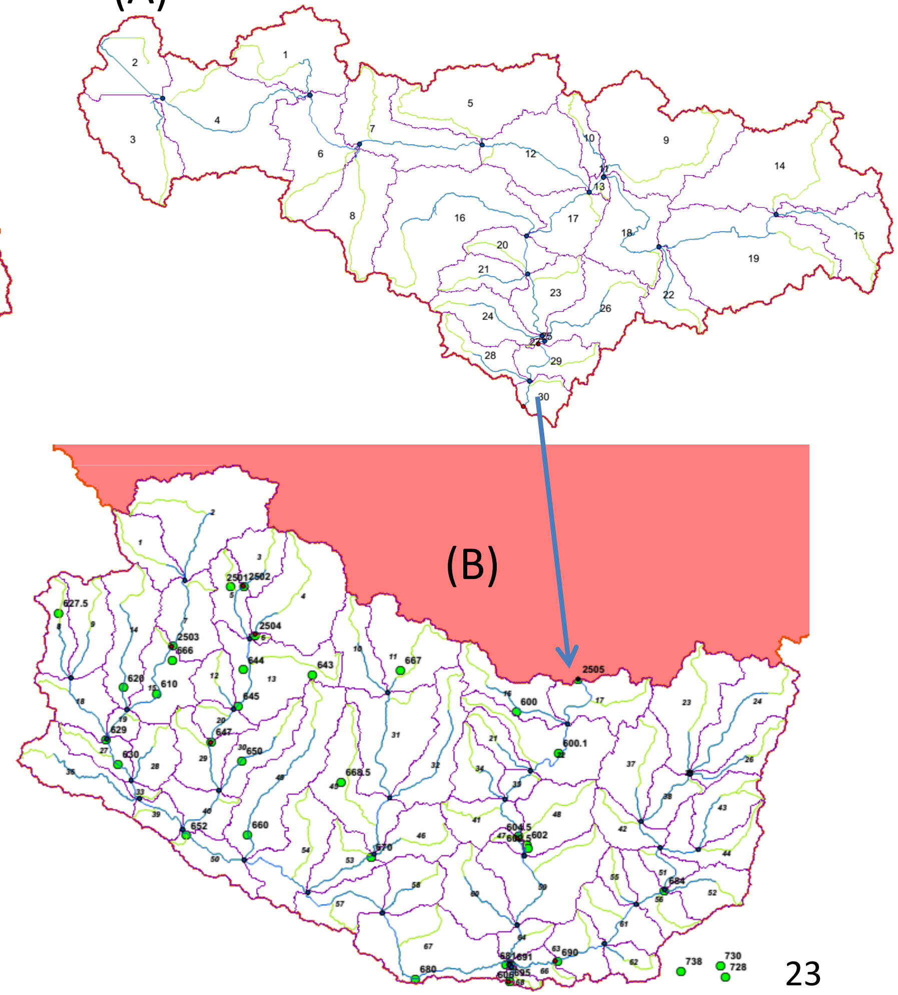
Hydrological Analysis : SWAT modelling (4)

Koshi River basin
(A) Tibetian part
(B) Nepalese part

- **Model setup for Koshi River basin**



(A)

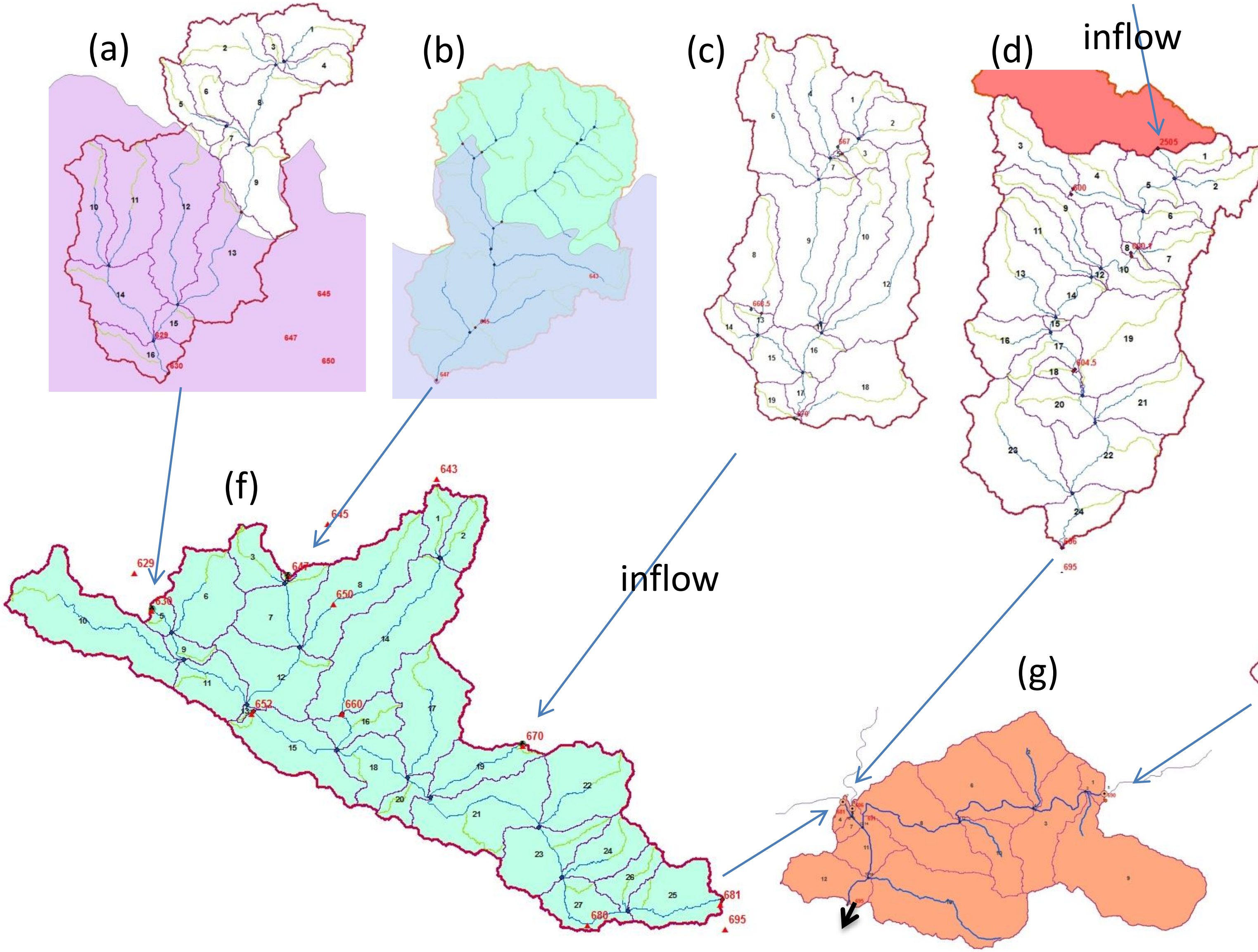


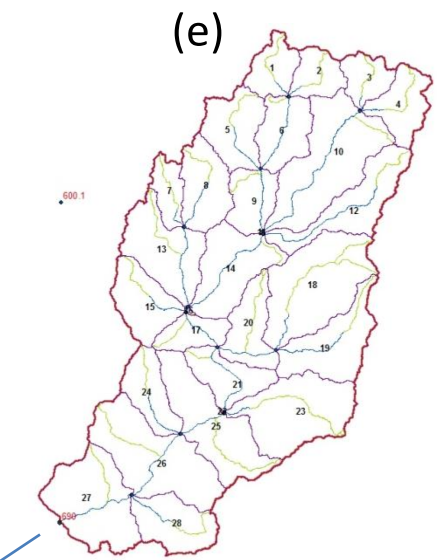
- Part of Koshi River basin
- Large part of basin area from Tibet –Arun
- Tibetan Part is significant
- No data available (used satellite data)

Hydrological Analysis : SWAT modelling (5)

- **SWAT Model setup for several basins of Koshi River basin**

Koshi River basins
(a) Bhote Koshi
(b) Tama Koshi
(c) Dudh Koshi
(d) Arun
(e) Tamor
(f) Sun Koshi
(g) Chatara

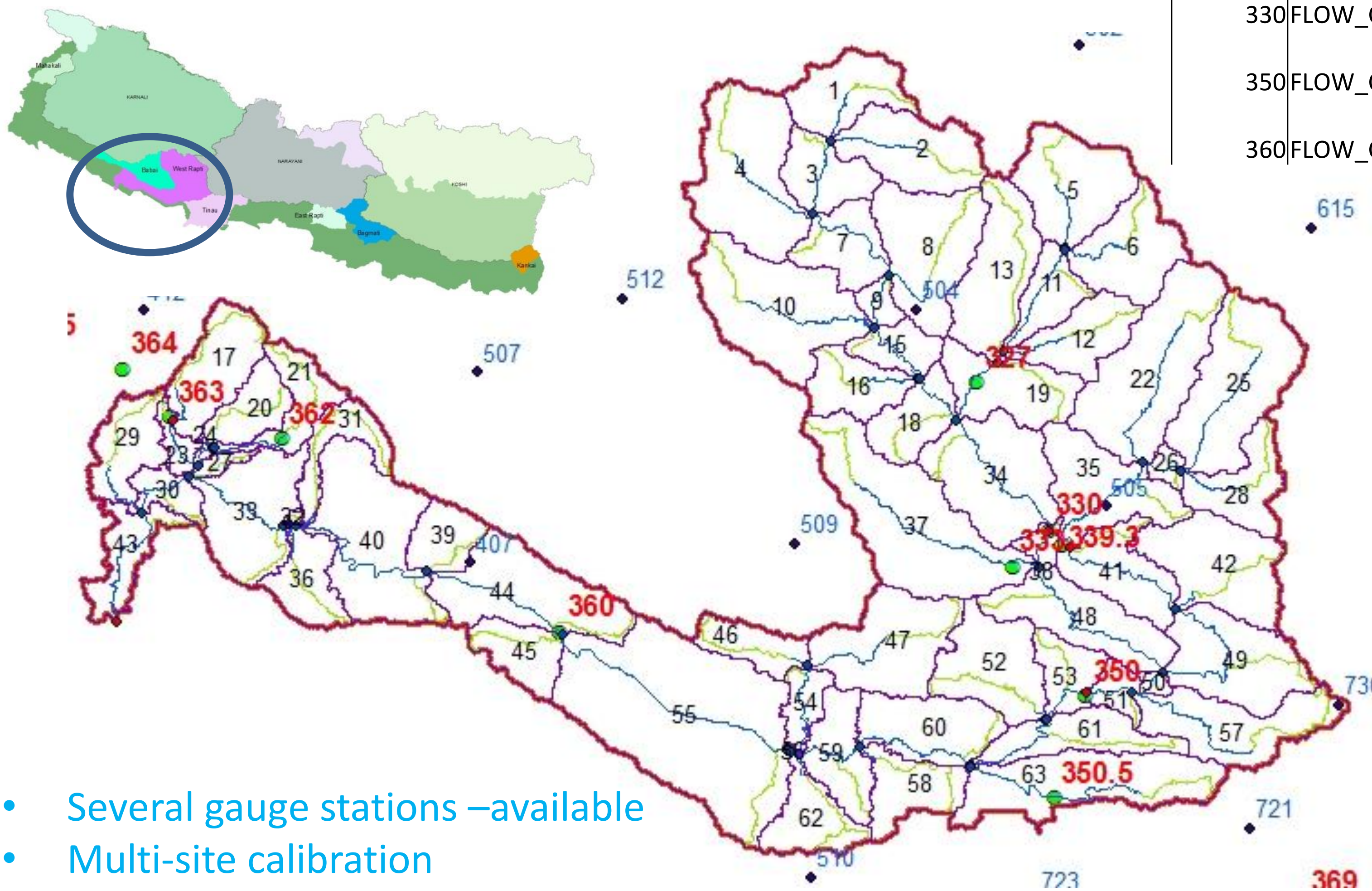




Hydrological Analysis : SWAT modelling (6)

- **SWAT Modelling in West Rapti River basin**

Stations	Name
330	FLOW_OUT_330
350	FLOW_OUT_350
360	FLOW_OUT_360



- Several gauge stations –available
- Multi-site calibration

Hydrological Analysis : SWAT modelling (7)

- **SWAT Model performance measures of Koshi basin and West Rapti basin**

- Statistical measures and graphical plot
- 9 years of streamflow data from 1990 to1998 -calibration
- 8 years, from 1999 to 2006 -validation.
- A warm up period of 1 year 1990 used to calibrate model.

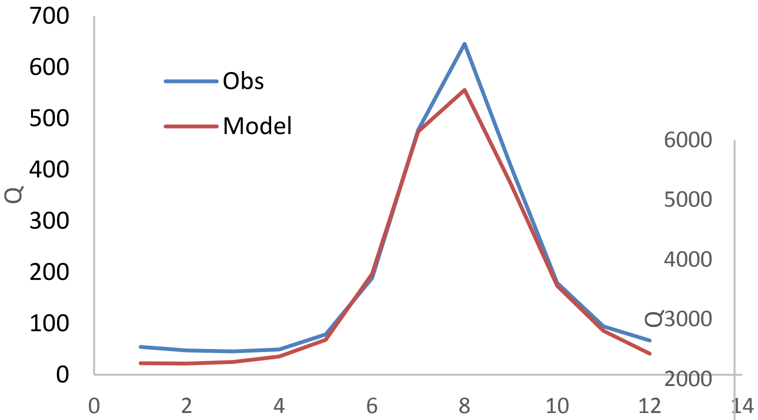
Basins		Stations	Name	Period	NS	RMSE	MSE	MAE	SAE	PBIAS	IVF	mass balance
Koshi	Arun	600.1	FLOW_OUT_6001	Cal	0.78	119.99	14398	94.16	9040	9.70	0.90	2522
				Val	0.71	114.11	13021	79.81	7662	-1.91	1.02	-423
		6045	FLOW_OUT_6045	Cal	0.77	211.50	44732	157.90	15158	31.09	0.69	13297
				Val	0.67	265.50	70492	202.03	19395	40.11	0.60	18925
		606	FLOW_OUT_606	Cal	0.64	309.23	95622	253.53	24338	39.54	0.60	22620
				Val	0.67	224.93	50592	198.84	19088	34.20	0.66	17497
	Dudh Koshi	670	FLOW_OUT_670	Cal	0.82	101.57	10317	52.48	5038	5.75	0.94	1098
				Val	0.70	141.79	20105	88.43	8490	15.16	0.85	3178
	Bhote Koshi	630	FLOW_OUT_630	Cal	0.92	57.71	3330	37.46	3596	13.50	0.87	2503
				Val	0.95	45.12	2036	33.35	3202	9.17	0.91	1725
	Tama Koshi	647	FLOW_OUT_647	Cal	0.89	57.98	3362	37.45	3595	9.86	0.90	1401
				Val	0.87	55.68	3100	36.13	3468	-1.65	1.02	-213
	Sun Koshi	681	FLOW_OUT_681	Cal	0.93	189.42	35878	112.86	10835	-13.03	1.13	-8309
				Val	0.93	203.72	41503	133.50	12816	-4.88	1.05	-3352
		660	FLOW_OUT_660	Cal	0.44	59.11	3494	37.96	2278	52.31	0.48	2217
				Val	0.26	74.40	5535	50.27	603	58.70	0.41	598
		652	FLOW_OUT_652	Cal	0.92	145.98	21311	79.47	7629	0.63	0.99	263
				Val	0.76	340.36	115848	186.77	17930	29.18	0.71	16369
	Tamor	690	FLOW_OUT_690	Cal	0.83	177.95	31665	119.51	11473	-2.70	1.03	-982
				Val	0.87	178.19	31752	110.61	10619	16.62	0.83	7078
		684	FLOW_OUT_684	Cal	0.91	87.62	7677	64.69	2329	-3.55	1.04	-367
				Val	0.83	102.59	10524	78.15	7502	-15.02	1.15	-3453
	Chatara	695	FLOW_OUT_695	Cal	0.89	477.06	227582	348.21	33428	20.73	0.79	31150
				Val	0.88	600.65	360778	360.01	34561	19.40	0.81	31580

West Rapti	330	FLOW_OUT_330	**Cal**	0.78	36.56	1336.34	23	2252.65	14.56	0.85
			Val	0.81	40.09	1607.03	22	2093.65	12.02	0.88
	350	FLOW_OUT_350	**Cal**	0.92	36.19	1309.38	23	2182.09	-0.08	1.00
			Val	0.65	121.51	14765.53	43	4116.46	21.97	0.78
	360	FLOW_OUT_360	**Cal**	0.94	41.90	1755.50	28	2652.80	-0.89	1.01
			Val	0.95	36.28	1315.93	24	2258.87	1.61	0.98

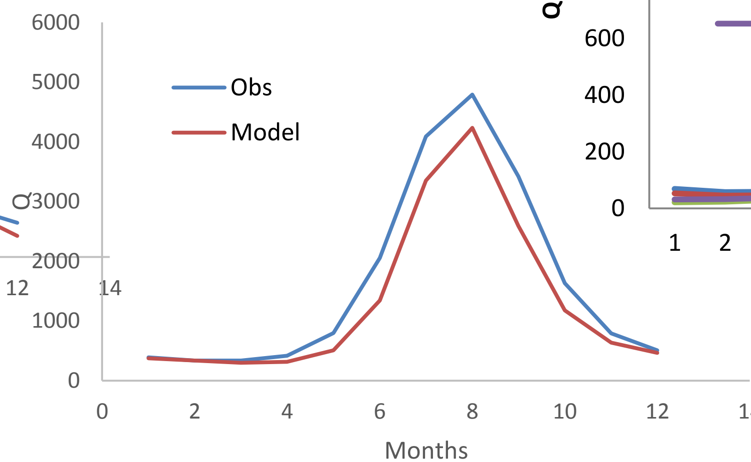
Hydrological Analysis : SWAT modelling (8)

- Graphical plots (Mean monthly hydrographs)

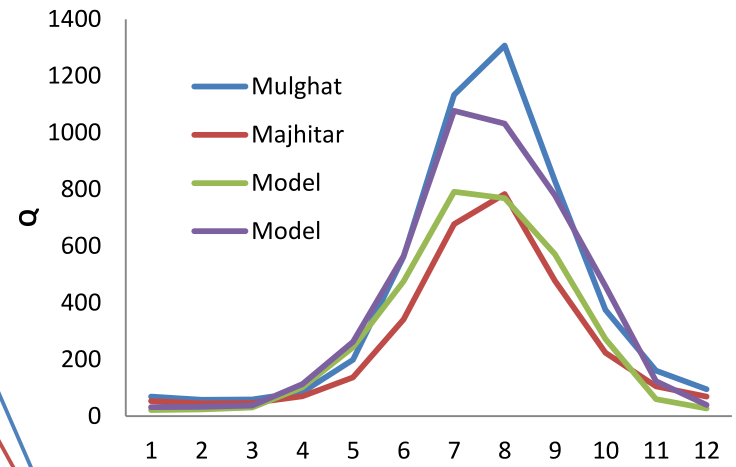
Bhotekoshi



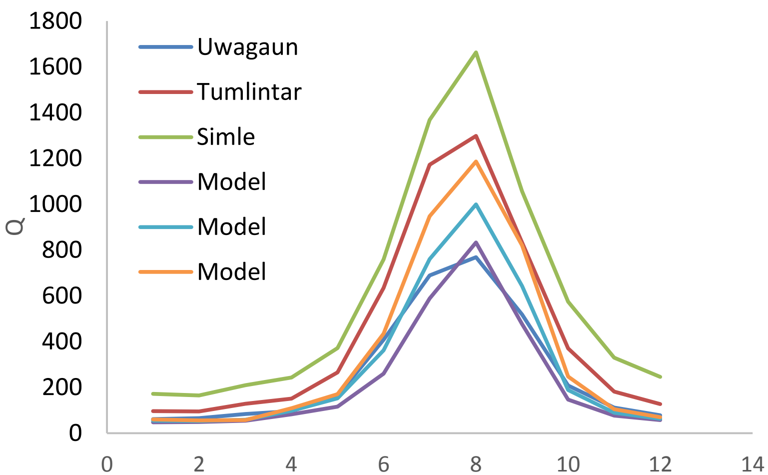
Chatara



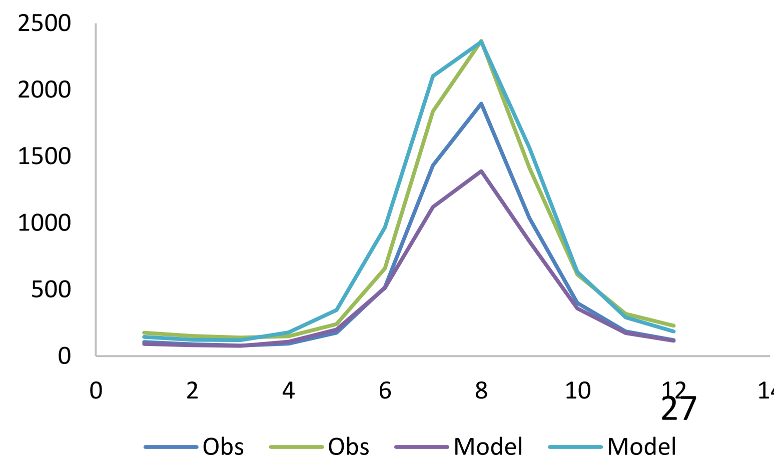
Tamor



Arun

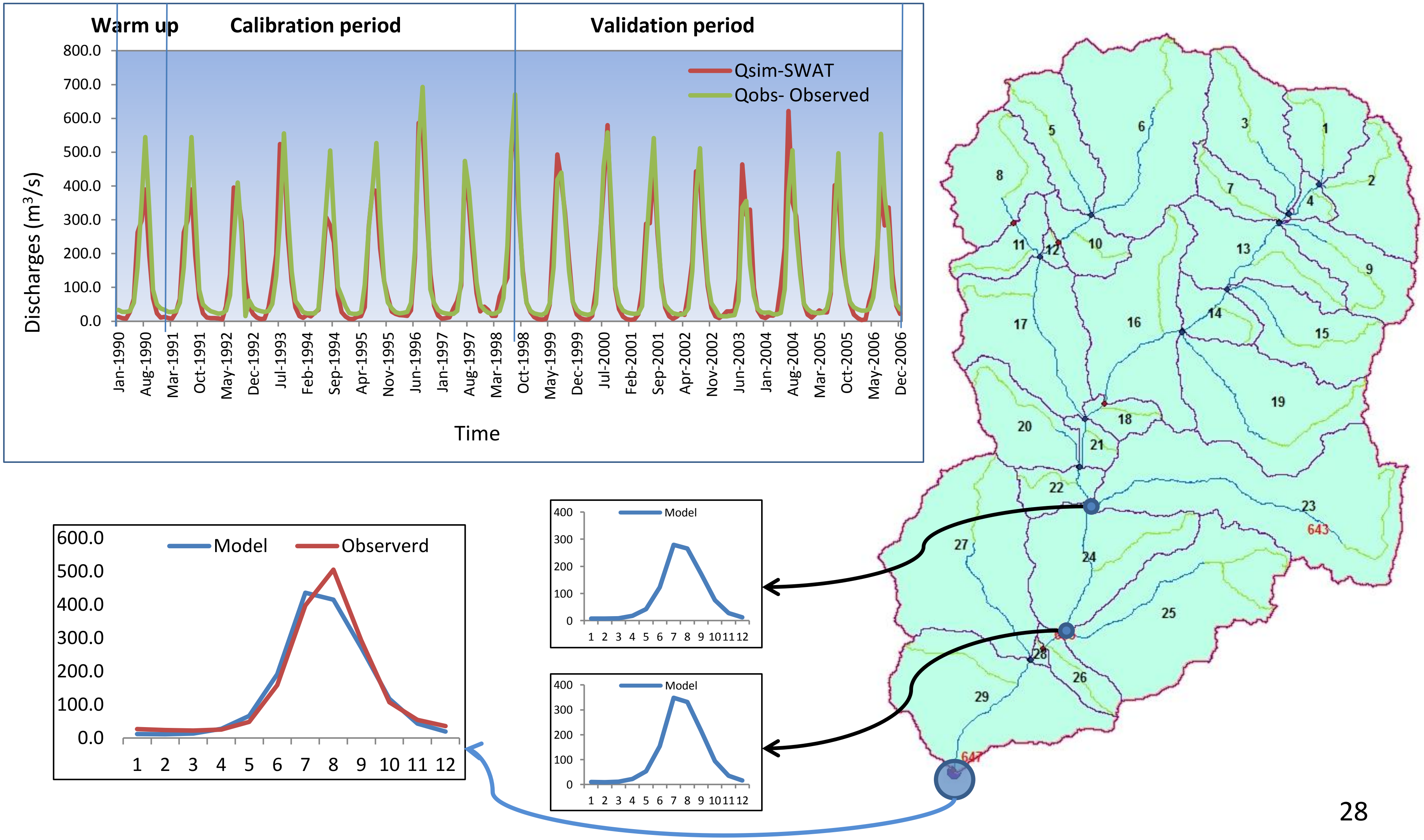


Sunkoshi



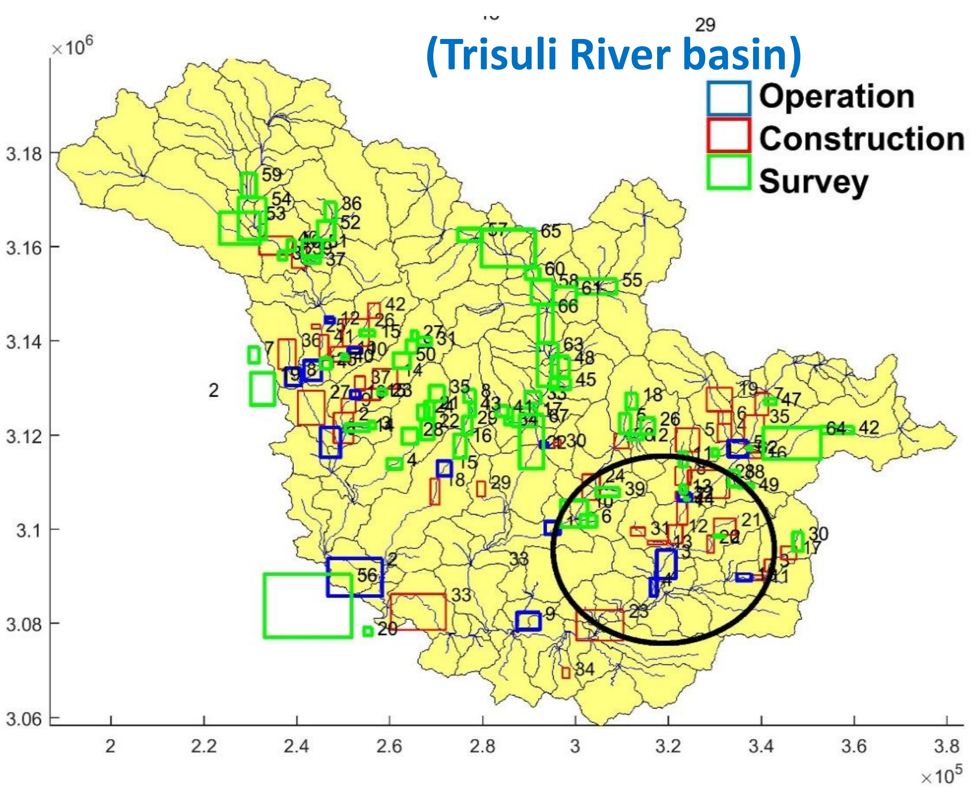
Hydrological Analysis : SWAT modelling (9)

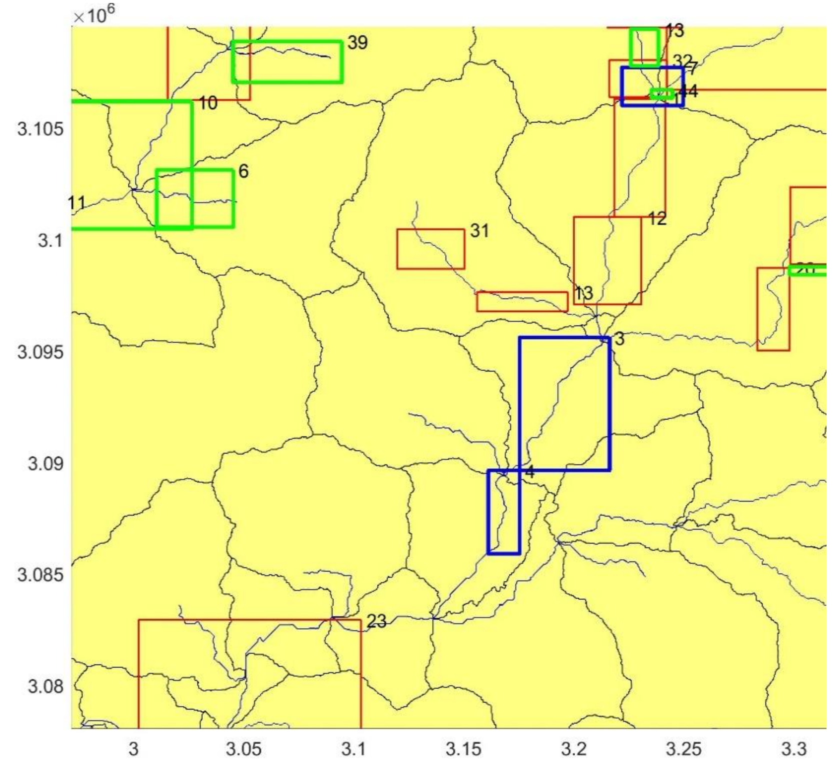
- **Estimation of stream flow in an ungauged site**



Project Spotting(1)

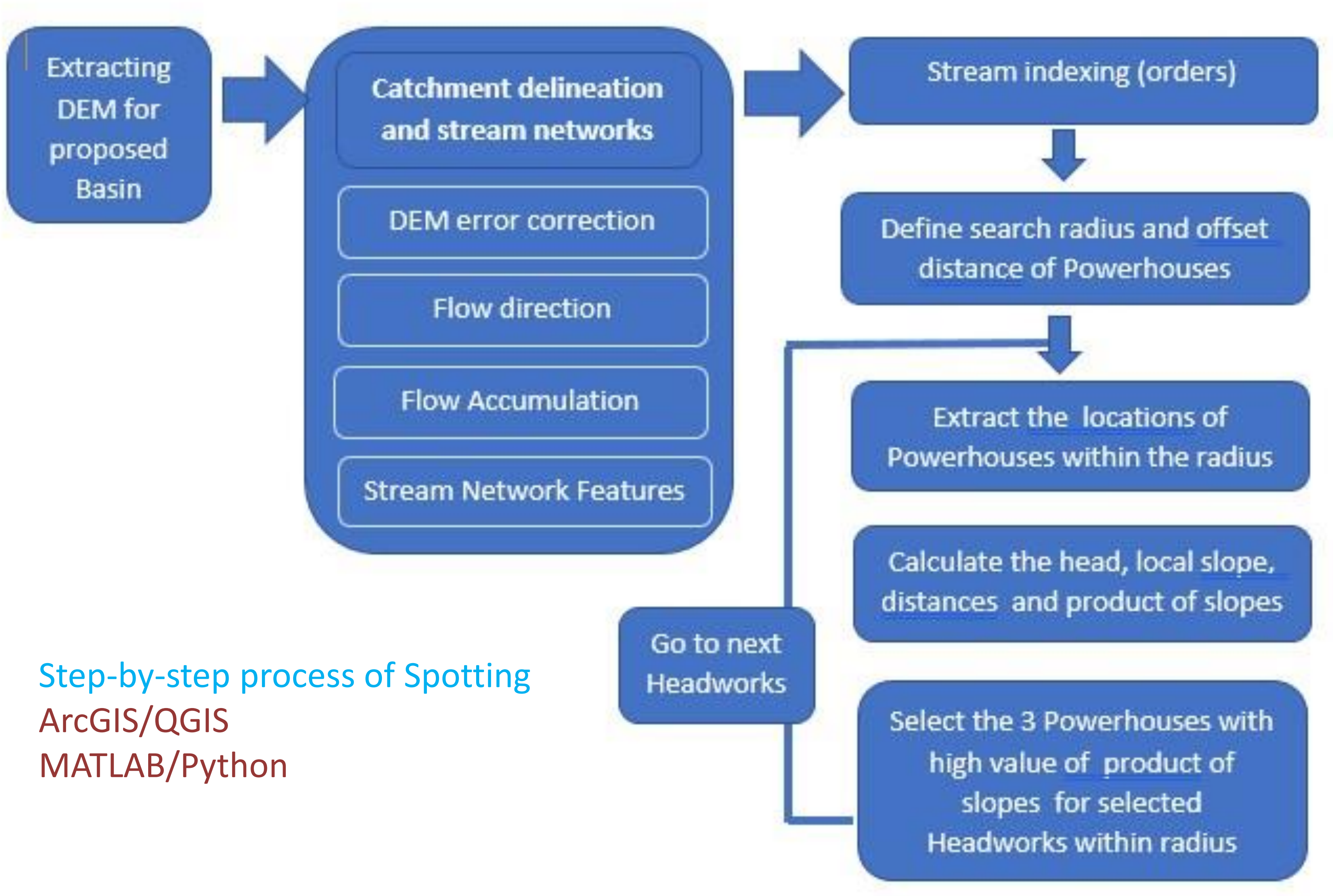
- Identification of individual projects
- Current licensing trend of DoED (project isolation)





- Basin wise optimum hydropower potential
- Spotting in whole basin

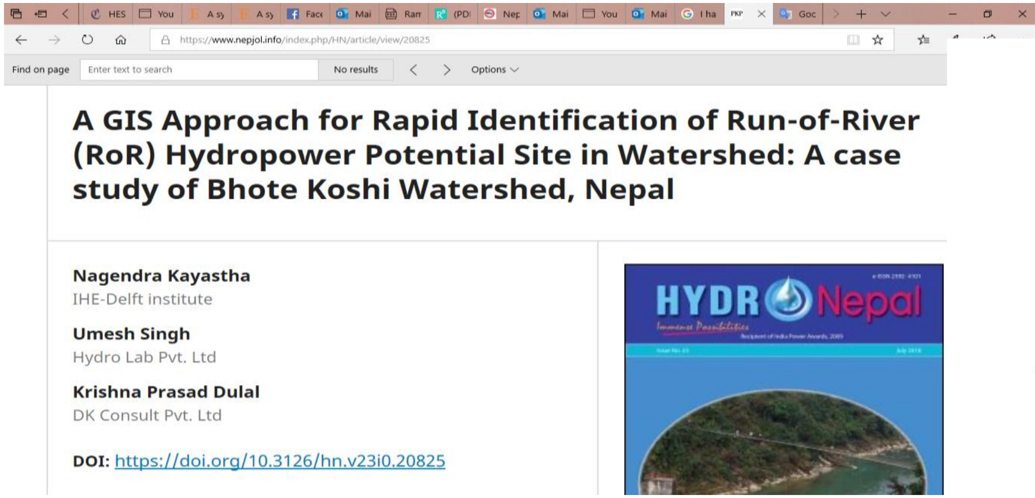
Project spotting (2)



Step-by-step process of Spotting
ArcGIS/QGIS
MATLAB/Python

Project spotting (3)

- Project spotting based on method (Kayastha et al, 2018)



A GIS Approach for Rapid Identification of Run-of-River (RoR) Hydropower Potential Site in Watershed: A case study of Bhote Koshi Watershed, Nepal

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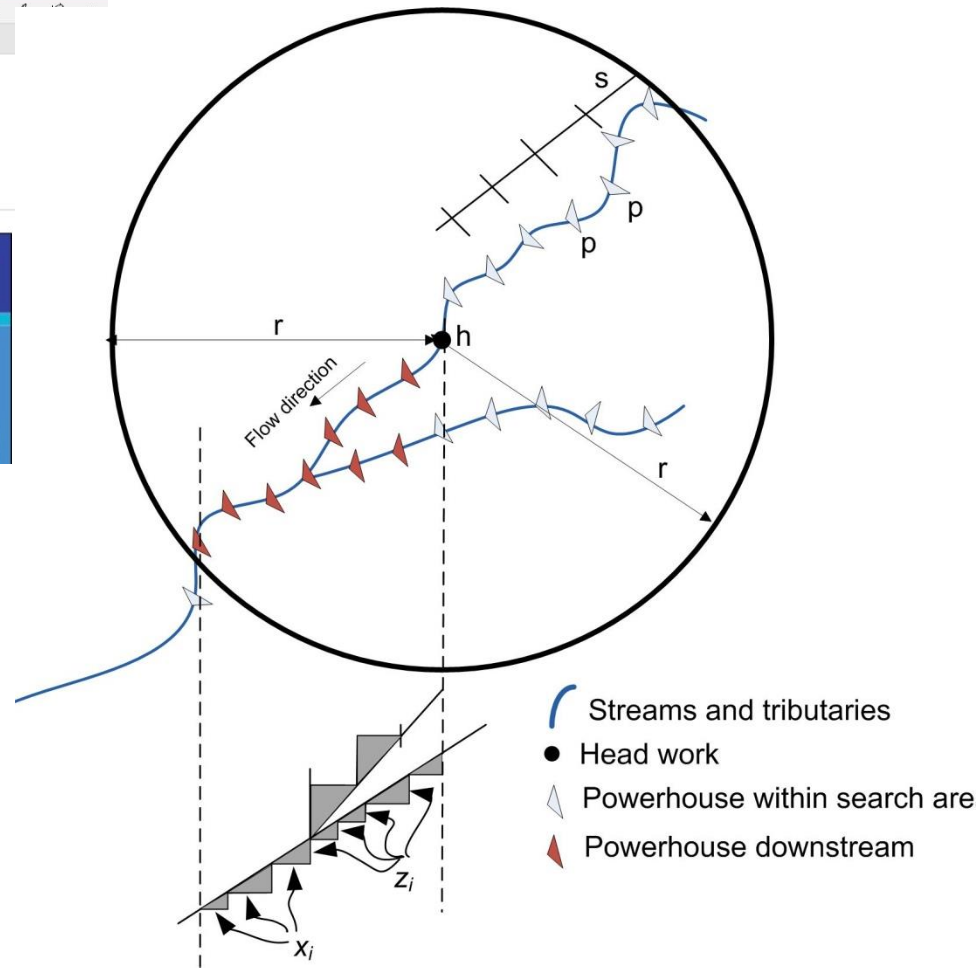
DOI: https://doi.org/10.3126/hn.v23i0.20825



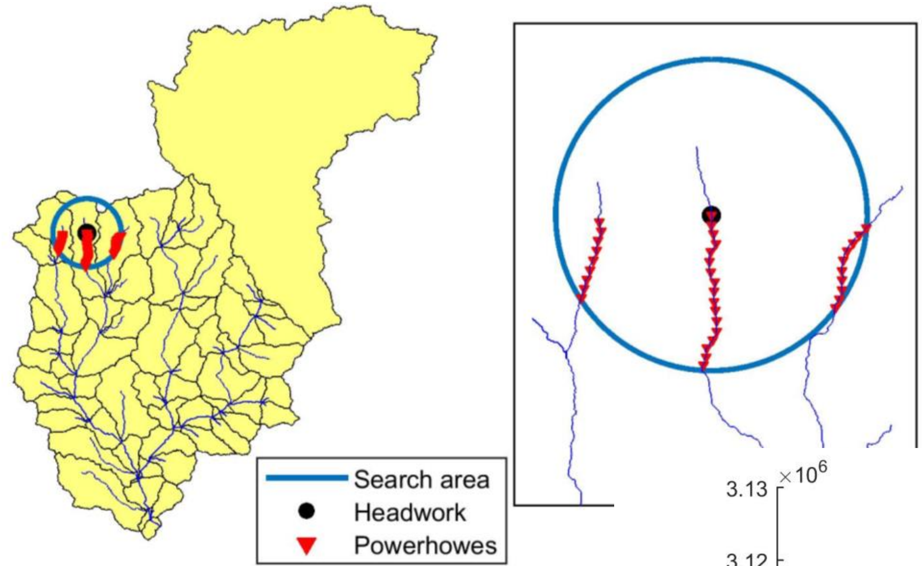
- Streams–discretized in equal interval
- Search radius = 10km @ 500 m interval for mainstream (Main rivers – bigger size of project is identify)
- Search radius = 4 km @ 200 m interval for tributaries

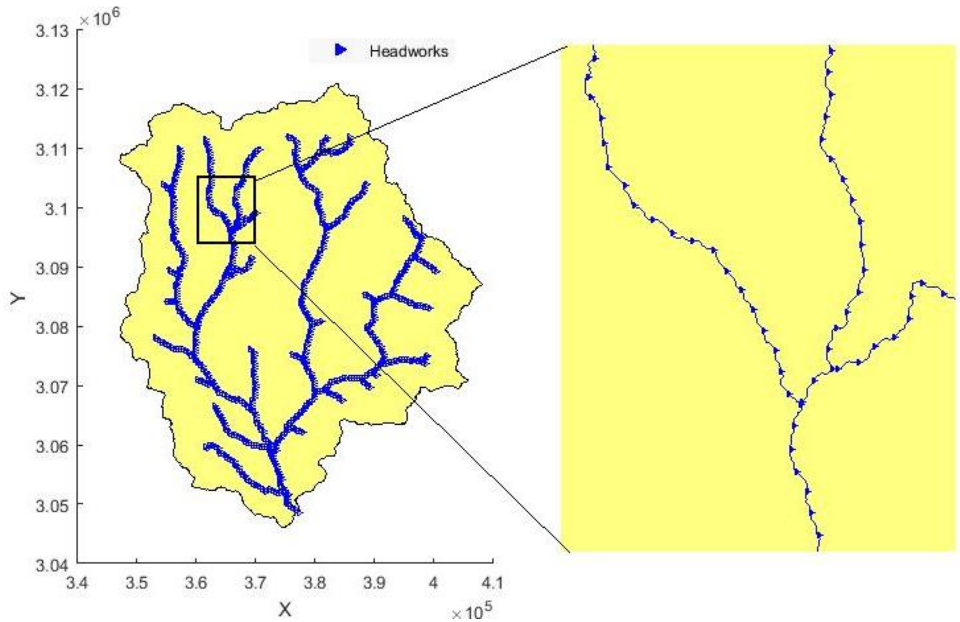
Project spotting (4)

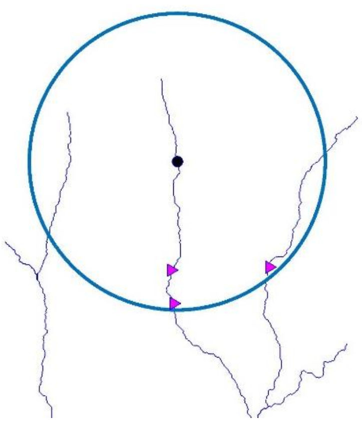
- Project spotting algorithm

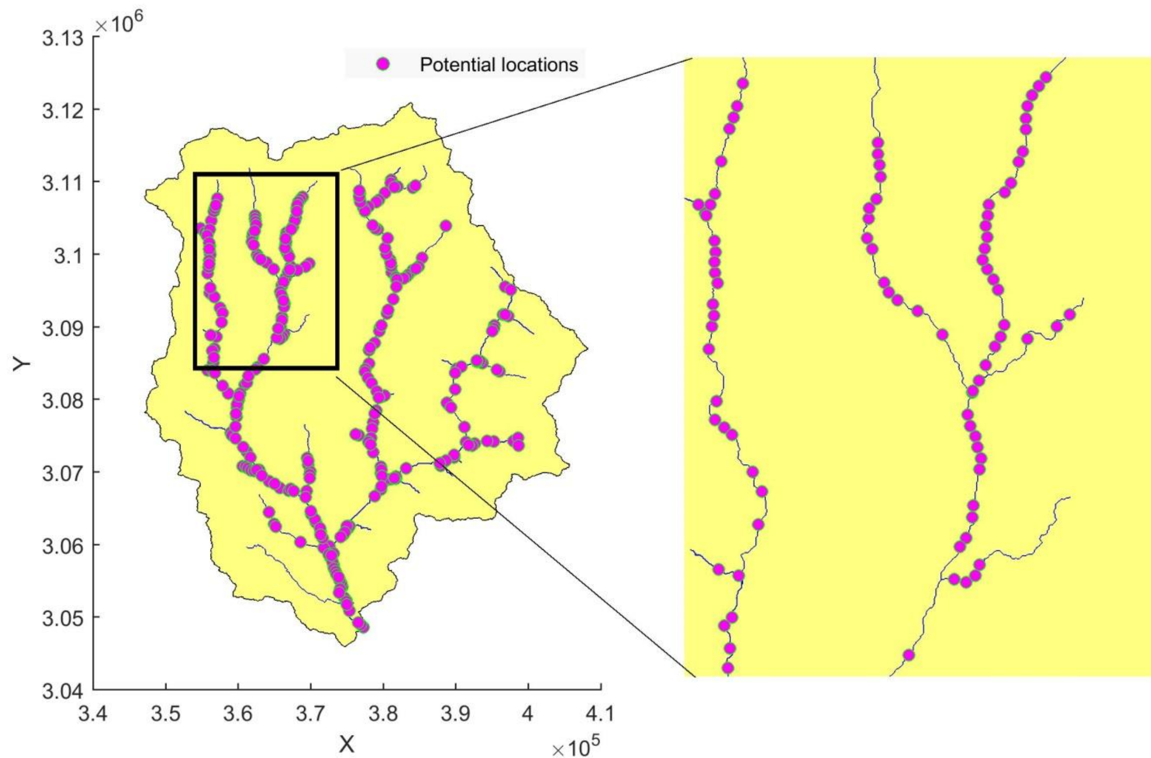
Project spotting (5)

- Project spotting algorithm









Project spotting (6)

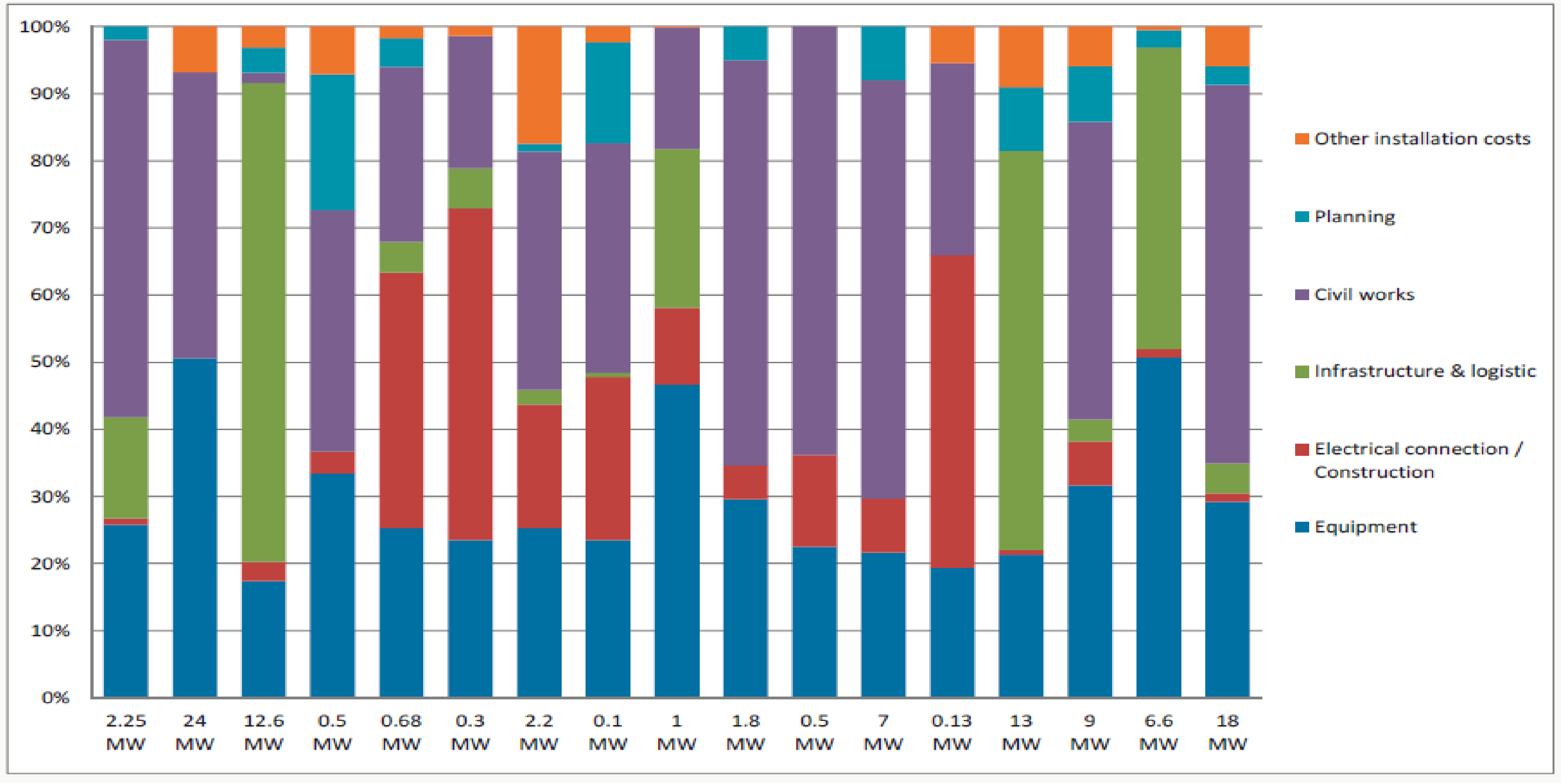
- Project spotting algorithm (database)
- Attributes of identified HW and PH

SN	X	Y	Z	fr	to	sot	inx	Slen	SN	HL	Lslope	THL	ArcLength	PSS	SHortLength
1	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	1308	5573	985	4296
1	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	939	3500	537	2557
1	397194.9	3095281	1899	14	18	1001	9	500	1	154	0.308	1206	4500	371	3407
2	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	1303	5073	981	3810
2	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	934	3000	534	2083
2	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	1138	10138	426	6413
3	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	1159	4573	873	3396
3	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	790	2500	452	1669
3	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	994	9638	372	6019
4	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	985	4073	742	2940
4	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	616	2000	352	1229
4	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	820	9138	307	5619
5	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	954	3573	718	2496
5	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	585	1500	335	826
5	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	789	8638	295	5248
6	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	802	3073	604	2125
6	396561.4	3095875	2298	14	18	1001	7	500	1	286	0.572	433	1000	248	422
6	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	637	8138	238	4845
7	397861.5	3094673	1698	14	18	1001	12	73.0421	1	55	0.75299	655	2573	493	1771
7	397246.3	3091505	1621	19	24	2016	10	500	16	-187	0.374	490	7638	183	4423
7	396823.8	3091692	1492	19	24	2016	11	500	16	-129	0.258	677	7138	175	4191

THL = Total head, ArcLength = Assumed Canal/ pipe length
ShortLength = Assumed tunnel length

Cost analysis (1)

- **Size of the Project Vs Cost Illustration**
- Cost distribution of hydropower project is site specific

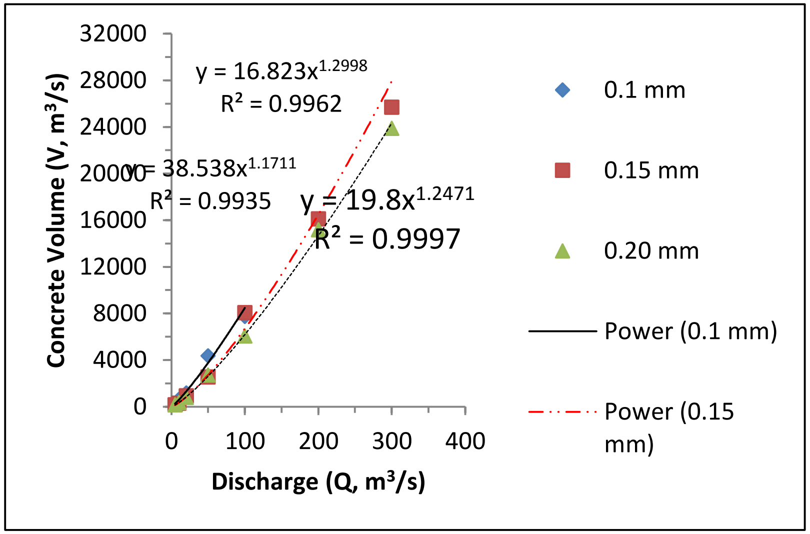


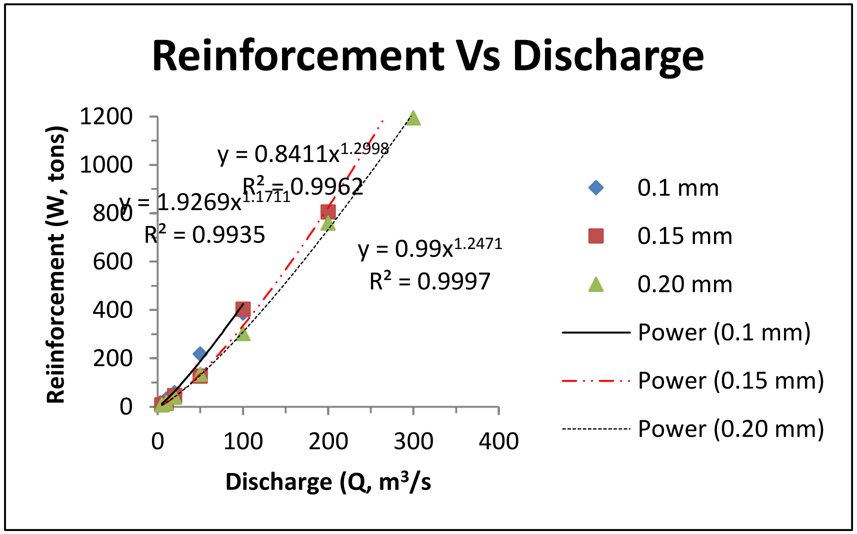
Source: IRENA 2012

- Project component of individual spotted project should be assessed

Cost Analysis(2)

- **Standardized technique**
- Design of identified individual projects in whole basin –no possible
- Standardized technique are used (based on function of discharges , e,g (Andarodi, 2000)
- Example of one project component
- discharge –material quantity -cost





Cost and Benefit analysis

- **Energy Sheet**

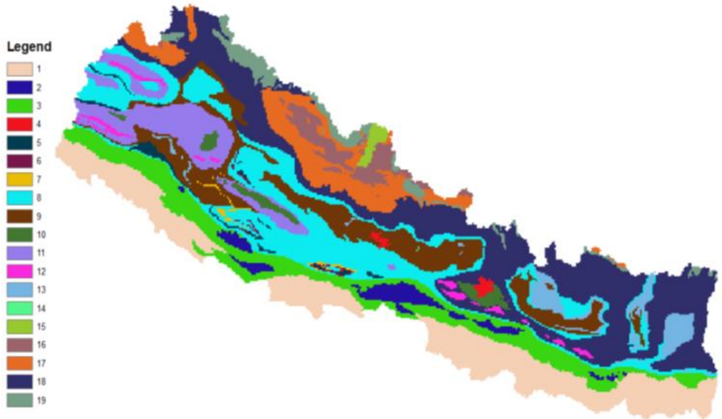
Energy Generation Table			Kaligandaki100								
Nepali Month		Discharge for Pow er Generation (m^3/sec)	Net Head	Monthly Efficiency	Monthly Pow er (KW)	Monthly Generation Before Outage & Losses	Outage Including Losses (KWh)	Net Available Energy (KWh) (Contact Energy)	Rate	Amount	
	A	C	D	E	F	G	H	I			Loss %
Jan	31	29.34	663.31	0.864	164998	122758198	6137910	116620288	**8.40**	979,610,423	**5**
Feb	28	25.83	663.31	0.864	145268	97620317	4881016	92739301	8.40	779,010,132	5
March	31	26.18	663.31	0.864	147222	109533354	5476668	104056686	8.40	874,076,162	5
April	30	43.66	663.31	0.864	245516	176771814	8838591	167933224	8.40	1,410,639,078	5
May	31	91.82	663.31	0.864	516359	384171374	19208569	364962805	8.40	3,065,687,564	5
June	30	101.11	663.31	0.864	568607	409396774	20469839	388926935	4.80	1,866,849,288	5
July	31	101.11	663.31	0.864	568607	423043333	21152167	401891166	4.80	1,929,077,598	5
Aug	31	101.11	663.31	0.864	568607	423043333	21152167	401891166	4.80	1,929,077,598	5
Sep	30	101.11	663.31	0.864	568607	409396774	20469839	388926935	4.80	1,866,849,288	5
Oct	31	87.62	663.31	0.864	492751	366606570	18330329	348276242	4.80	1,671,725,961	5
Nov	30	49.25	663.31	0.864	277002	199441693	9972085	189469609	**4.80**	909,454,122	**5**
Dec	31	37.21	663.31	0.864	209274	155700205	7785010	147915194	8.40	1,242,487,633	5
Total	365					**3277483739**		**3113609552**	**5.95**	**18,524,544,847.03**	

- HA-discharges –Energy calculation
- Total cost of the project
- Benefit from the project; Energy sells
- Cost benefit; BC ratio; IRR; NPV

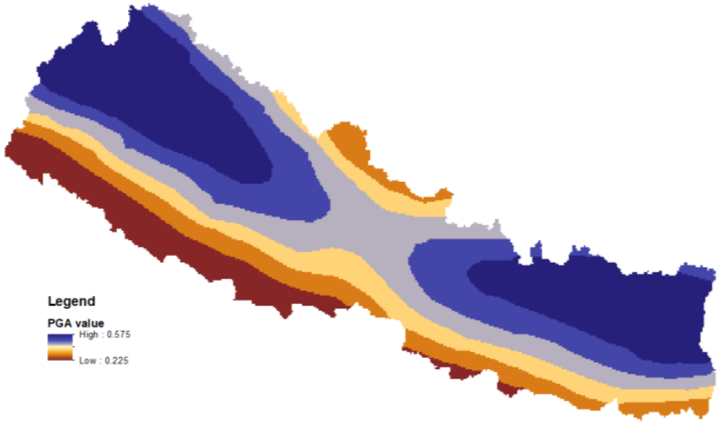
Dry Energy (kWh)	994227499	31.93%
Wet Energy (kWh)	2119382053	68.07%
Total Energy (kWh)	3113609552	100 %

Multi-Criteria Analysis

- Technical aspects: Geology, Natural disaster, infrastructure and market
- Project Screening -MCA



Regional geological map of Nepal



Earthquake hazard map

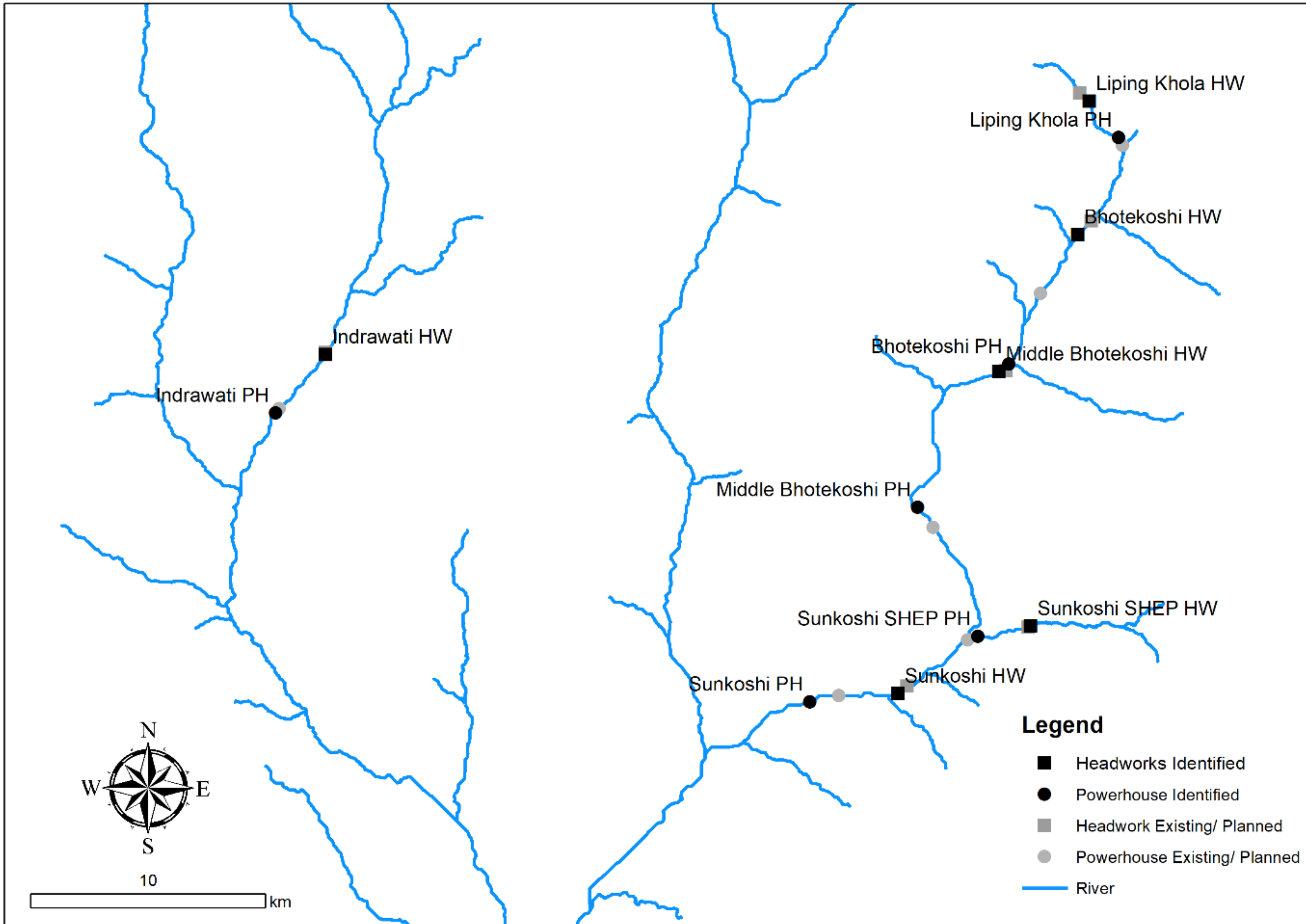
Sub - criteria	Weight age	Unit	Score		
			100	50	25
Type of rock	0.5	[-]			
Distance from the major faults	0.5	km			
Vicinity of the nearest road head	0.5	km/ MW			
Vicinity of the nearest Regional market	0.5	km/ MW			
Length of transmission line (equivalent to 132 kV)/ MW	1	km/ MW			
Percentage of area of glacier and glacial lakes in the catchment	0.5	[-]			
Earthquake hazard	0.5	PGA value			

Techno-Economical feasible projects

Basins	Identified projects	Techno-economically feasible
Karnali	58263	3496
Gandaki	23568	2828
Koshi	21756	1653
Babai	4893	587
Bagmati	6843	753
East Rapti	3723	149
Kamala	3750	150
Kankai	1857	111
Mahakali	23226	232
Tinau	9213	737
West Rapti	6564	722
Total	163,656	11,418

- Scoring - threshold – screening – TE feasible projects
- Identify the mutually exclusive projects through optimization

Techno-Economical feasible projects (validation)



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Dr. Hari Krishna Shrestha and Dr. K. N Dulal –are acknowledged for the part of contribution in HA.

Results: Comparison at different flow

Basin	Power Potential (MW)	
	Q_{40}	Q_{20}
Koshi	28,810	81,244
Karnali	25,466	55,945
Gandaki	24,135	63,160
Mahakali	3,021	10,959
Bagmati	1,043	3,187
Rapti	999	4,227
Babai	446	1,731
Kankai	411	1,253
Kamala	255	863
Tinau	158	633
Bakaiya	94	278
Mechi	62	158
Total	**84,900**	**223,640**