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Valuing Hydrological Outputs as Water Related Ecosystem Services under Present and Future Climate Scenarios for Godavari basin

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- Objectives
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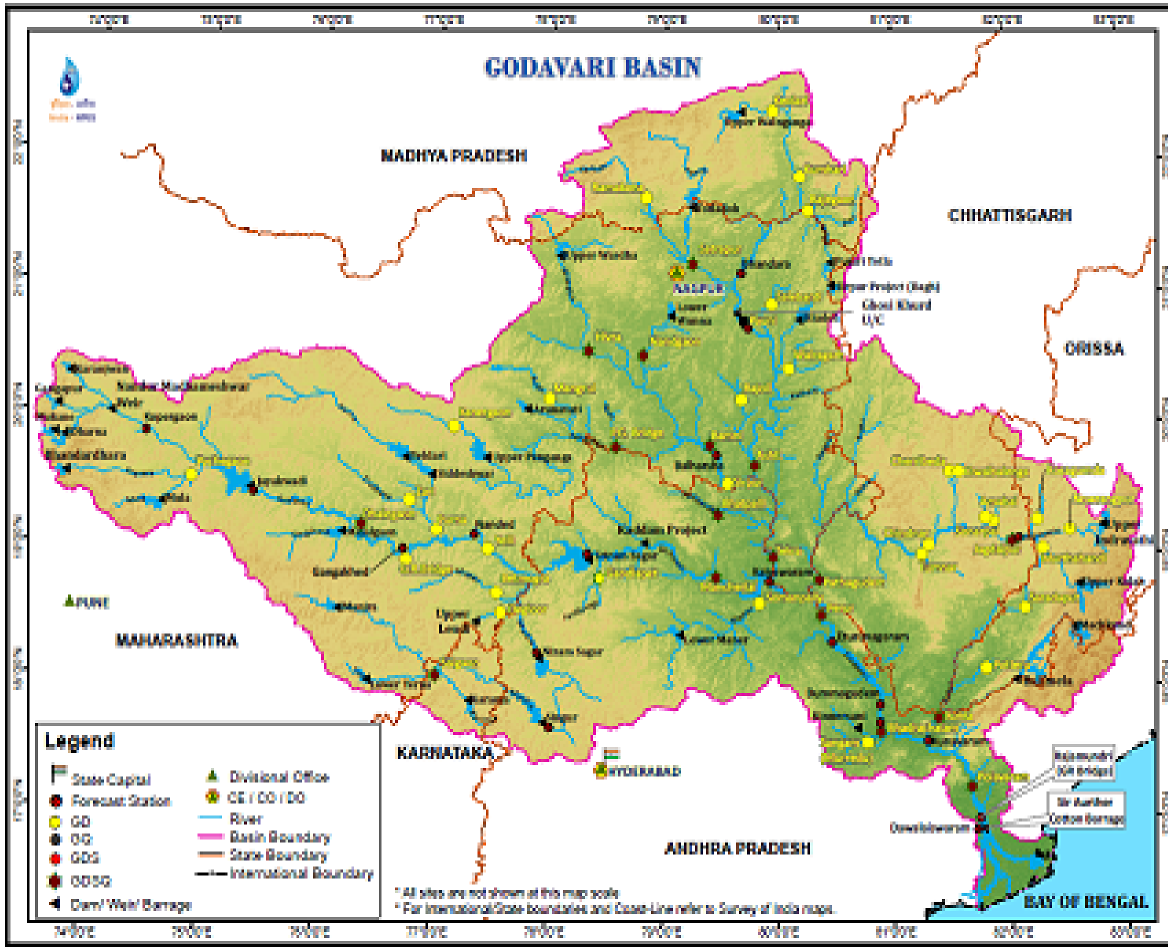
Introduction

- Ecosystem services can be defined as the ability that nature has to **supply benefits and quality of life to humankind.**
- These benefits are distinguished into four categories:

    1. Supporting,
    2. Provisioning,
    3. Regulating and
    4. Cultural services (Millennium Ecosystem Assessment 2003).

- Key ecosystem services are also connected to the hydrological cycle in the river basin, for example **water purification, water retention, and climate regulation.**

Study area



Total Area : 3 12 812 km^2 , Flows 1465 km

Second largest river in India

Annual rainfall 600-3000 mm

3000 TMC water with 75% dependability.

921 Dams, 28 Barrages, 18 Weirs, 1 Anicut, 62 Lifts and 16 Powerhouses have been constructed

- **Severe drought and upcoming projects in the area** it is clear that the pressure will be influenced on water related ecosystem of the river.
- Understanding the **long term impact** of **climate, agriculture deforestation and anthropogenic effects** is crucial for service of Godavari basin.

Objectives

- Developing a **hydrological model** and accounting for **water related ecosystem services** in the analysis and to provide information on present and future flows in Godavari basin along spatial and temporal scale.

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Tools used to quantify water related ecosystem services

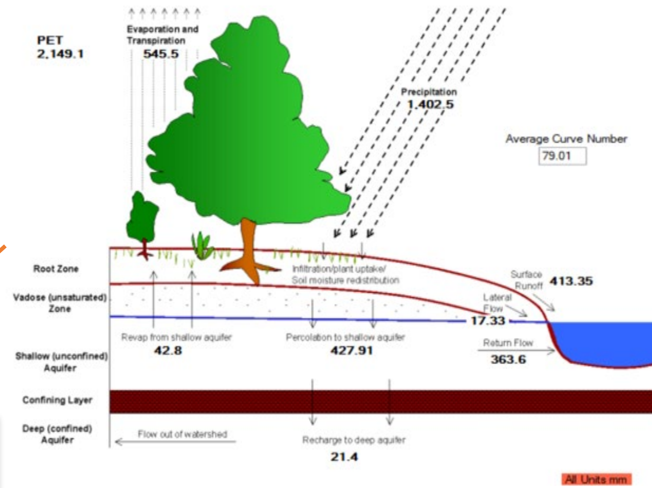
	SWAT	VIC	InVEST	ARIES
Key data inputs				
Precipitation	Daily	Hourly	Ave annual	Best avail
Topography	Yes	Yes	Yes	Yes
Soil type	Multi layer	Multi layer	Single layer	Single layer
Snow water equivalent	Yes	Yes	No	No
Key outputs				
Water yield	Daily	Hourly	Annually	No*
Evapotranspiration	Daily	Hourly	Annually	No*
Flows	Daily	w/routing model	No	Yes
Sediment retained	Yes	No	Yes	No*
Nutrients retained	Yes	No	Yes	No*

Table: showing basic inputs and outputs for water related Ecosystem service tools

Table: Summary of fresh water ecosystem service tools

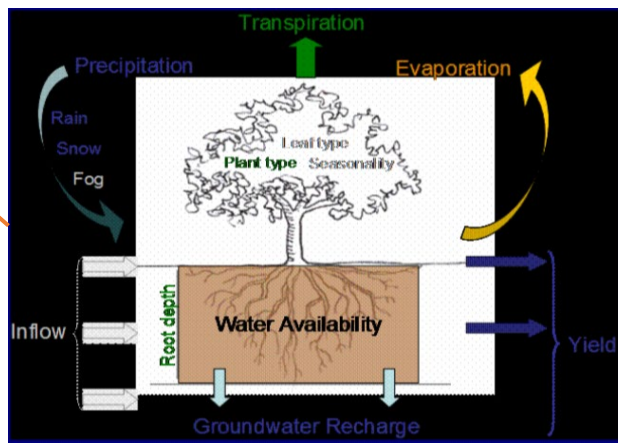
Model	Freshwater services	Time step	Scale	Platform
InVEST	Nutrient filtration, hydropower, irrigation, avoided reservoir sedimentation, storm peak mitigation	Annual	30m-10km grid cells	GIS
SWAT	Water yield, sedimentation, water quality	Daily	Sub-basin	Windows or GIS
VIC	Water yield	Hourly to daily	1-50 km grid cells	LINUX/ UNIX

GCM/RCM's



QSWAT

WATER RELATED ECOSYSTEM SERIVES OUTPUT



InVEST

Downscaling
to river basin

Godavari basin

Flow chart

Global Climate Model Data

- NetCDF
- ESPI grids
- Present and Future sources scenarios (CMIP5) CNRM

Downscaling with Bias correction

Godavari Basin

Data sets used

- **LULC**
- **ET**
- **DEM**
- **PAWC**
- **PPT**
- **Soil**

QSWAT

- Hydrological Modelling
- Calibration and Validation of model (SWAT – CUP)

InVEST

- Hydropower prediction
  - Water Yield
  - Water Consumption
  - Hydropower Evaluation
- Water Purification – Nutrition Retention Model
- Seasonal Water Yield

Comparing Outputs for Present and Future sources

Mapping and Prediction of Water related Eco-system sources

QSWAT- The QGIS interface for SWAT

- 166 sub-basins were formed in the entire Godavari basin
- The model was run from the period 1961 to 2000
- 3 years of warm period was considered
- For calibration of stream flow period of was considered
- Validation was done for stream flow was from 1990-2000
- 11 parameters namely CN, ALPHA_BF, GWQMIN, ESCO, GW_REVAP, SOL_AWC, SOL_K, EPCO, SURLAG, RCHRG_DP was considered for optimization using SWAT-CUP.

InVEST models to used in study

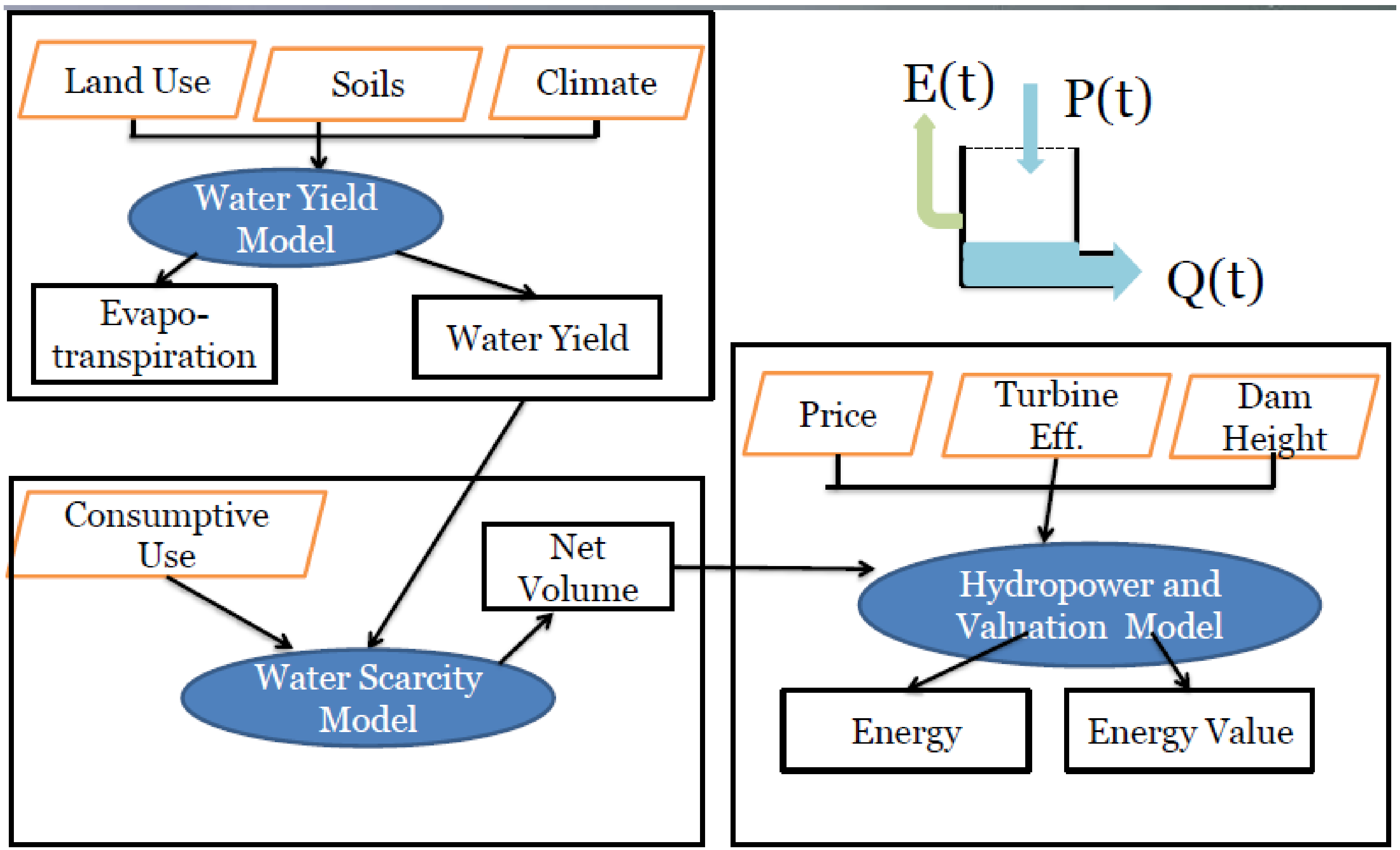
1. Hydropower production
   - **Water yield model**
   - **Water consumption**
   - **Hydropower valuation**

2. Water purification model
   - **Nutrient Retention**

Hydropower production

Required	Supply	Land use/land cover	Calculates pixel level yield as difference between precipitation and evapotranspiration	Annual average water yield (mm/watershed/yr, mm/sub-basin/yr)
		Annual average precipitation		
		Annual average reference evapotranspiration		
		Plant available water content		
		Evapotranspiration coefficient		
		Root depth		
		Effective soil depth		
		Zhang coefficient		
	Service	Consumptive use by LULC	Subtracts water consumed for other	Annual average water yield available for hydropower production (mm/watershed/yr, mm/sub-basin/yr)
		Watersheds above points of interest		
Optional	Value	Calibration coefficient	Estimates power generated by water available for hydropower	Energy production (KWH/watershed/yr, KWH/sub-basin/yr)
		Turbine efficiency		
		Reservoir fraction for hydropower		
		Average annual head		
		Hydropower production costs	Calculates ne present value of energy produced over lifetime of dam	Net present value (currency/watershed/yr, currency/sub-basin/yr)
		Hydropower price		
		Timespan		
		Discount rate		

Hydropower valuation model architecture



Key features

- InVEST estimates the annual average quantity and value of hydropower produced by reservoirs, and identifies how much **water yield or value** each part of the landscape contributes annually to hydropower production.
- Yield, as calculated by this step of the model, is then adjusted for other consumptive uses and applied to hydropower energy and value estimates.

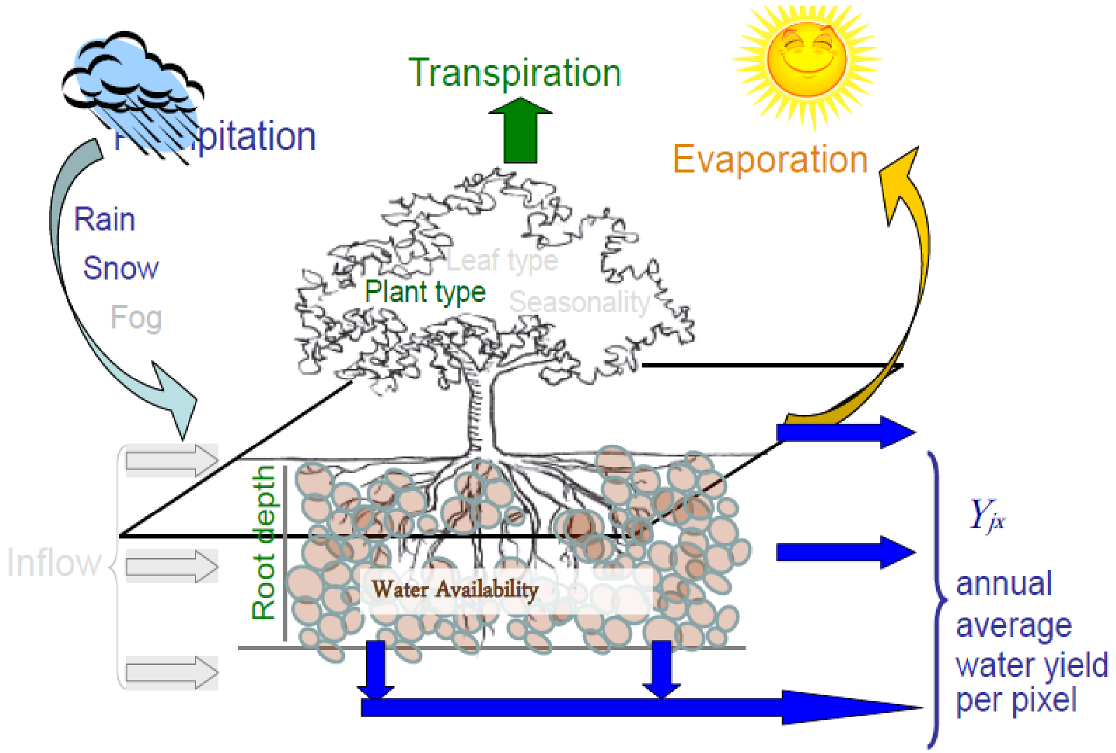


Figure:- water balance model used in the hydropower production model

Methodology employed

- The water yield model is based on the Budyko curve and annual average precipitation.
- Annual water yield Y (*x*) for each pixel on the landscape *x* as follows:

$$Y(x) = \left(1 - \frac{AET(x)}{P(x)}\right) \cdot P(x)$$

- **Realized Supply Model**
- This calculates the water inflow to a reservoir based on water yield and water consumptive use in the watershed(s) of interest.
- Consumptive use of water is taken into account and calculated as:

$$C = \frac{W - R}{n}$$

- Where, C = the consumptive use (/pixel),W= withdrawals (m^3/yr), R = return flows (m^3/yr), and n= number of pixels in a given land cover.

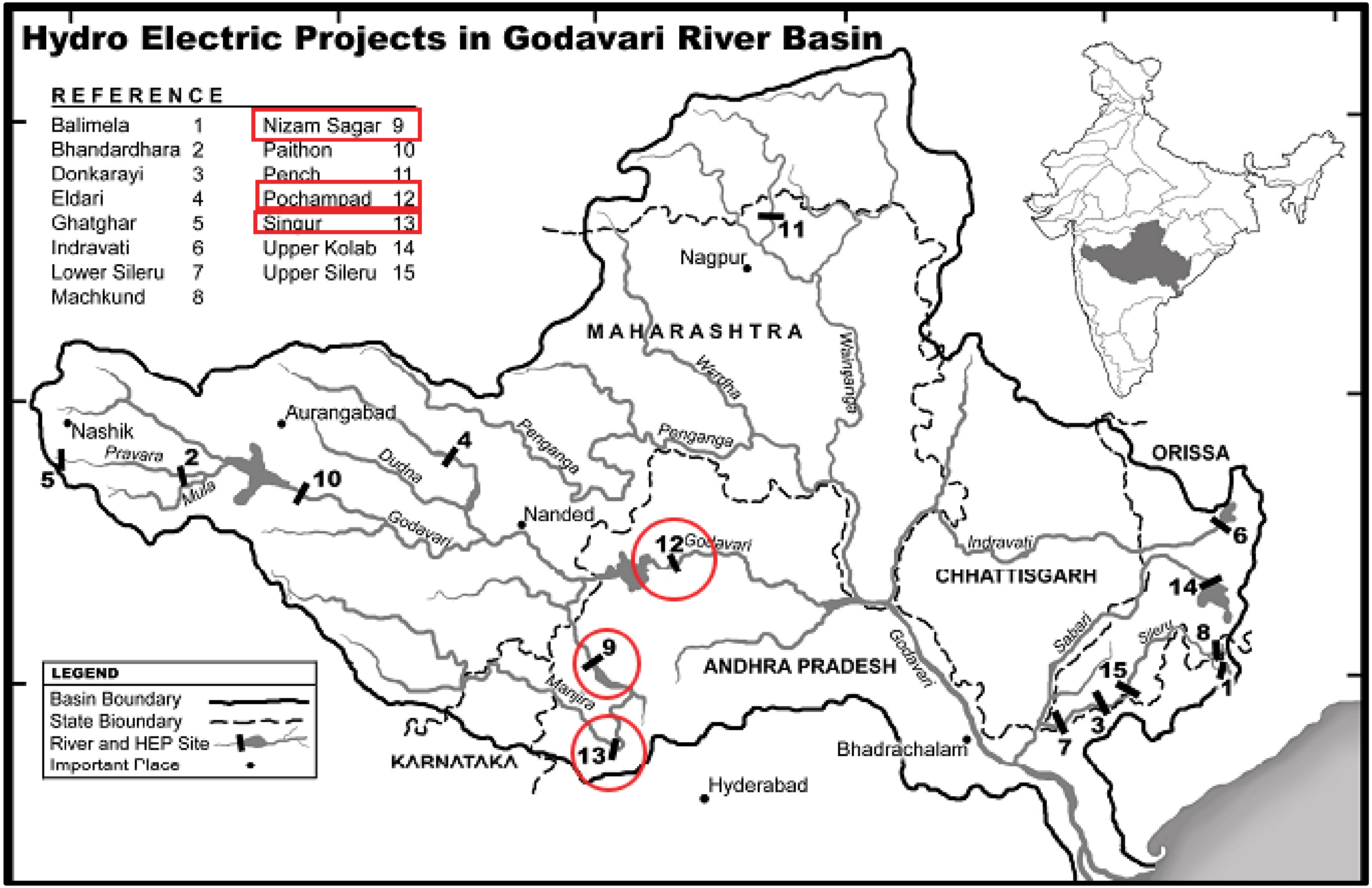
Water scarcity model

Required data

- Demand Table - A table of LULC classes, showing consumptive water use for each land use / land cover type.
- Consumptive water use is that part of water used that is incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the watershed water balance.

Outputs from the model

- consum_vol (m3): Total water consumption for each watershed.
- consum_mn (m3/ha): Mean water consumptive volume per hectare per watershed.
- rsupply_vl (m3): Total realized water supply (water yield – consumption) volume for each watershed.
- rsupply_mn (m3/ha): Mean realized water supply (water yield – consumption) volume per hectare per watershed.



Locations of Hydropower plant considered in the study for evaluation in the basin

Hydropower Production and Valuation Model

- The reservoir hydropower model estimates both the amount of energy produced given the estimated realized supply of water for hydropower production and the value of that energy.
- A present value dollar (or other currency) estimate is given for the entire remaining lifetime of the reservoir.

Data for hydropower evaluation:

Station_name	Ws_id	Time_span(years)	Discount(%)	Efficiency (%)	Fraction	cost	Height(m)	Kw_price (INR)
Singur	88	29	5	0.9	0.6	0	33	5
Nizamsagar	125	87	5	0.75	0.6	0	35.2	5
Sriramsagar	143	30	5	0.85	0.7	0	43	5

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Hydropower Production and Valuation Model

- The energy produced and the revenue is then redistributed over the landscape based on the proportional contribution of each sub-watershed to energy production.
- Final output maps show how much energy production and hydropower value can be attributed to each sub-watershed's water yield over the lifetime of the reservoir

This is the amount of ecosystem service in energy production terms.

- hp_energy (kw/timespan): Amount of energy produced by the hydropower station over the specified timespan that can be attributed to each watershed based on its water yield contribution.
- hp_val (currency/timespan): This shows the value of the landscape per watershed according to its ability to yield water for hydropower production over the specified timespan.

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Water purification model

Required	Supply	Land use/land cover	Calculates nutrient export and retention	Nutrient export (kg/watershed/yr, kg/pixel/yr) Nutrient retention (kg/watershed/yr, kg/pixel/yr)
		DEM		
		Water yield (output from Hydropower model; refer to Hydropower model for input data requirements)		
		Export co-efficient in kg/ha/yr (for nutrient(s) of interest)		
		Nutrient filtration efficiency (%)		
	Service	Allowed level of nutrient pollution	Subtracts retention equal to amount of allowed pollution	Water purification through ecosystem nutrient retention (kg/watershed/yr, kg/pixel/yr)
		Sub-watershed and watersheds shapfiles		
Optional	Value	Mean annual nutrient removal costs	Calculates present value of costs	Avoided treatment costs (currency/watershed/yr, currency/basin/yr)
		Lifespan (years)		
		Discount rate (%)		

Key features

- InVEST nutrient delivery model is to map nutrient sources from watersheds and their transport to the stream.
- The model uses a mass balance approach, describing the movement of mass of nutrient through space
- Represents the long-term, steady-state flow of nutrients through empirical relationships.
- Nutrient loads are determined based on the LULC map and associated loading rates.
- This spatial information can be used to assess the service of nutrient retention by natural vegetation.
- The retention service is of particular interest for surface water quality issues and can be valued in economic or social terms.

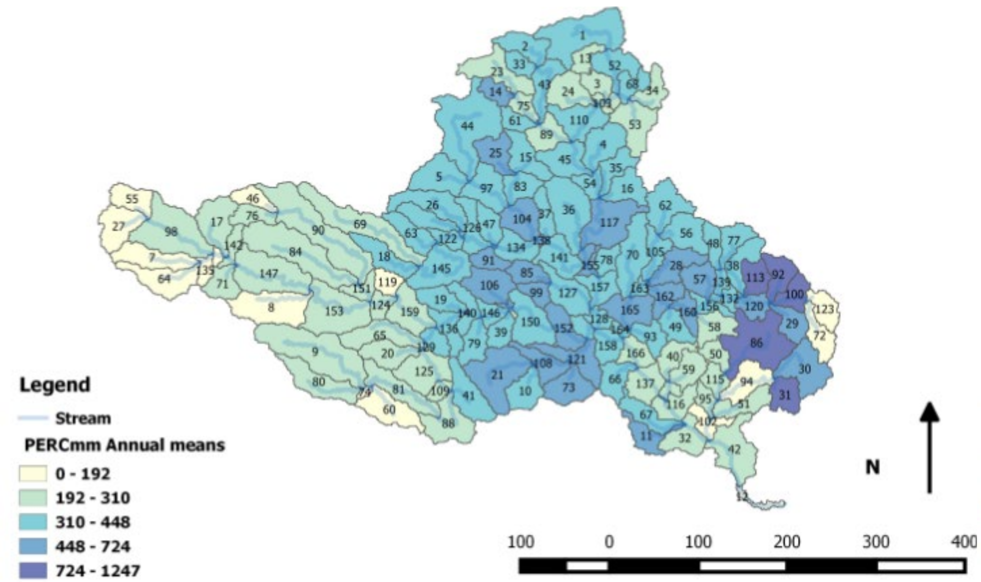
Nutrient Export

- Nutrient export from each pixel i is calculated as the product of the load and the NDR: In the NDR model, the nutrient export is calculated by

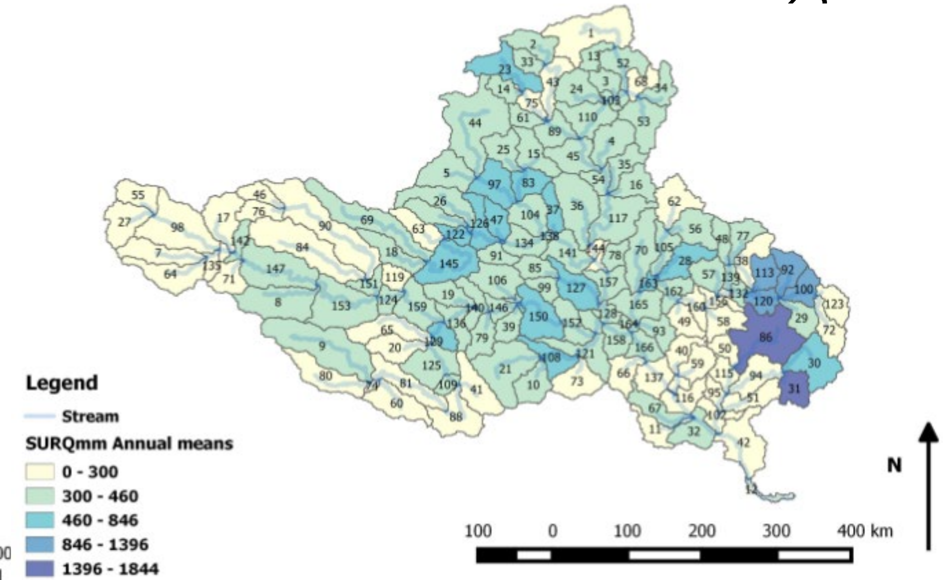
$$x_{exp_i} = load_{surf,i} \cdot NDR_{surf,i} + load_{subs,i} \cdot NDR_{subs,i}$$

- Total nutrient at the outlet of each user-defined watershed is the sum of the contributions from all pixels within that watershed:

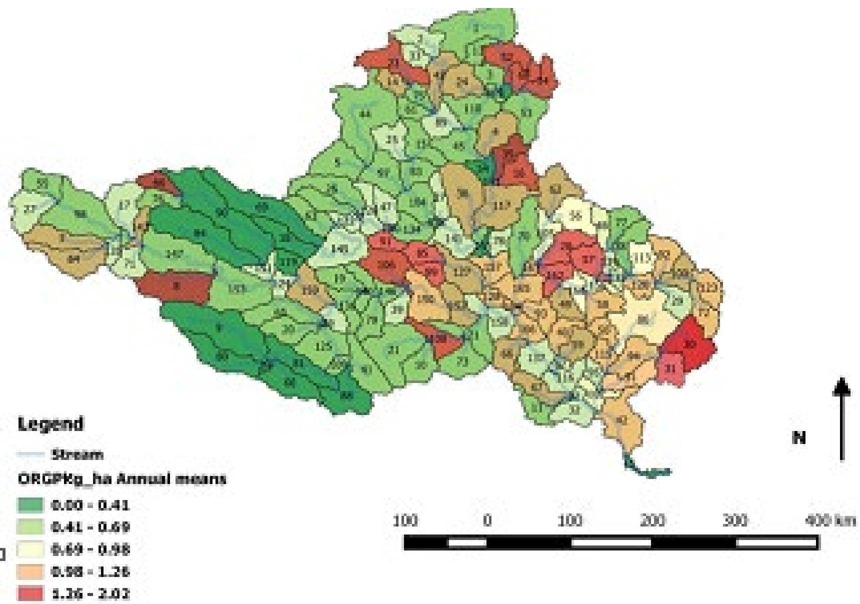
$$x_{exp_{tot}} = \sum_i x_{exp_i}$$



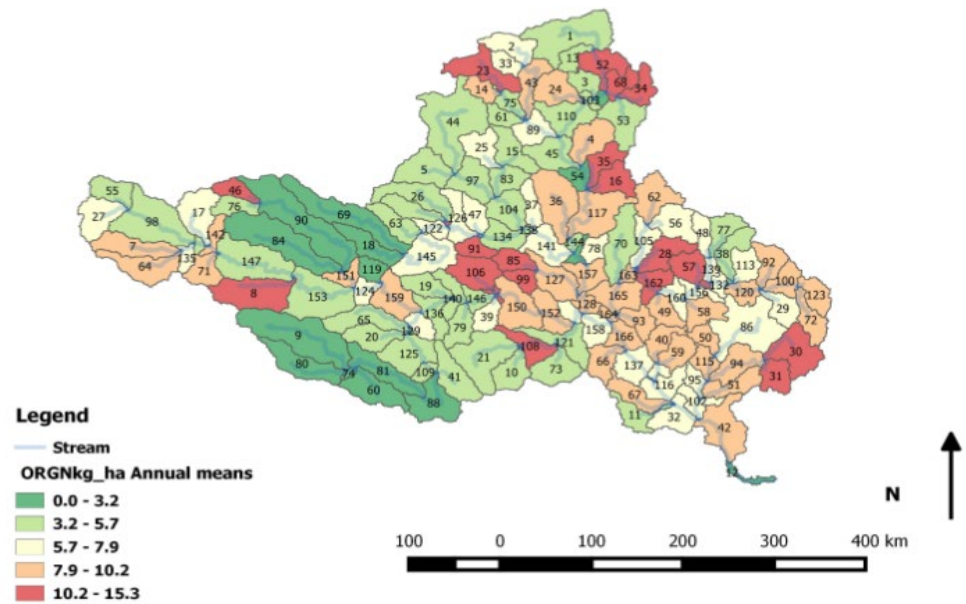
Annual average Precipitation from 1964-2000.



Annual average Runoff simulated from 1964-2000



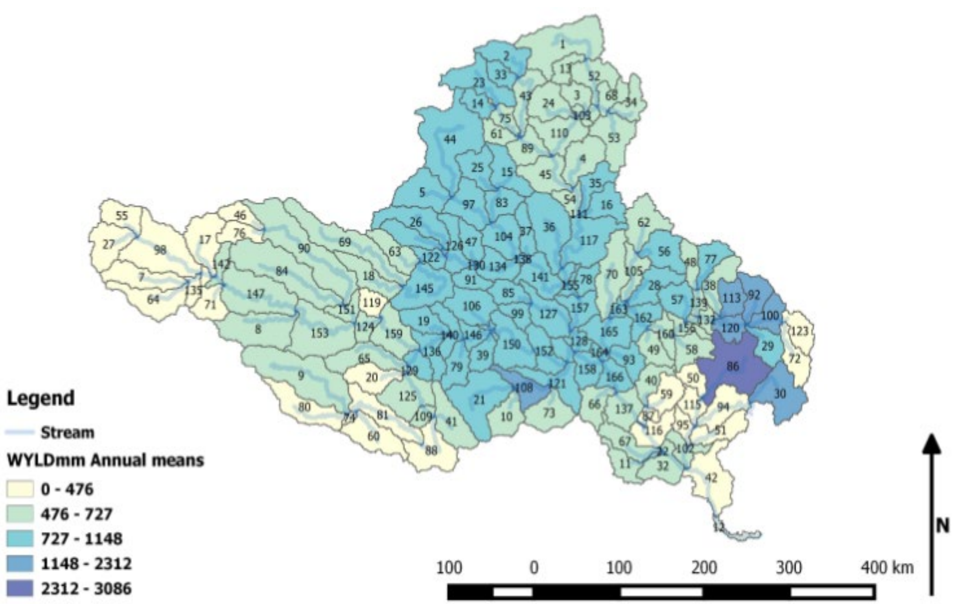
Annual average Phosphorous(kg/hectare).



Annual average Nitrogen(kg/hectare).

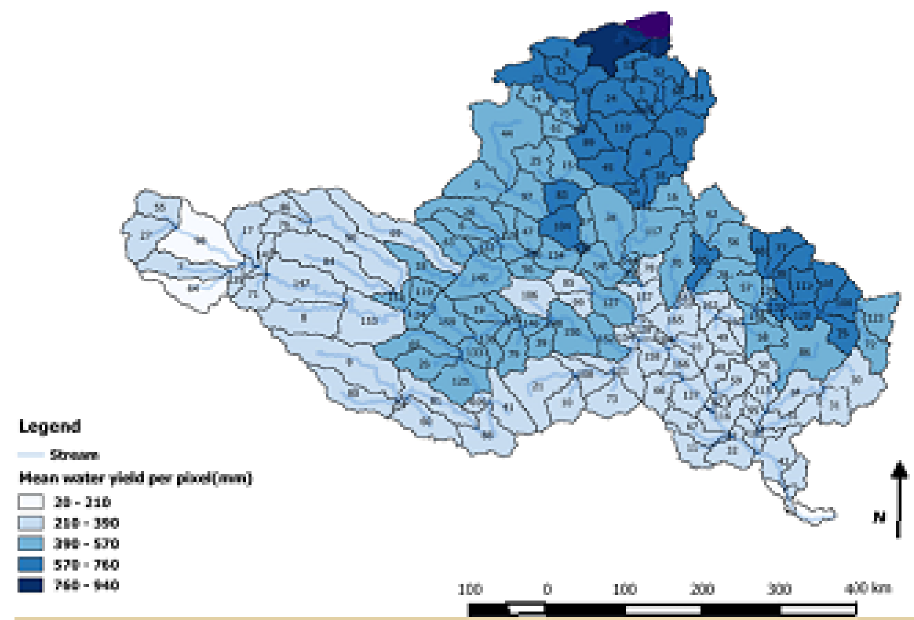
Annual mean Water yield obtained from SWAT and InVEST

SWAT



Annual average water yield simulated (1964-2000)

InVEST



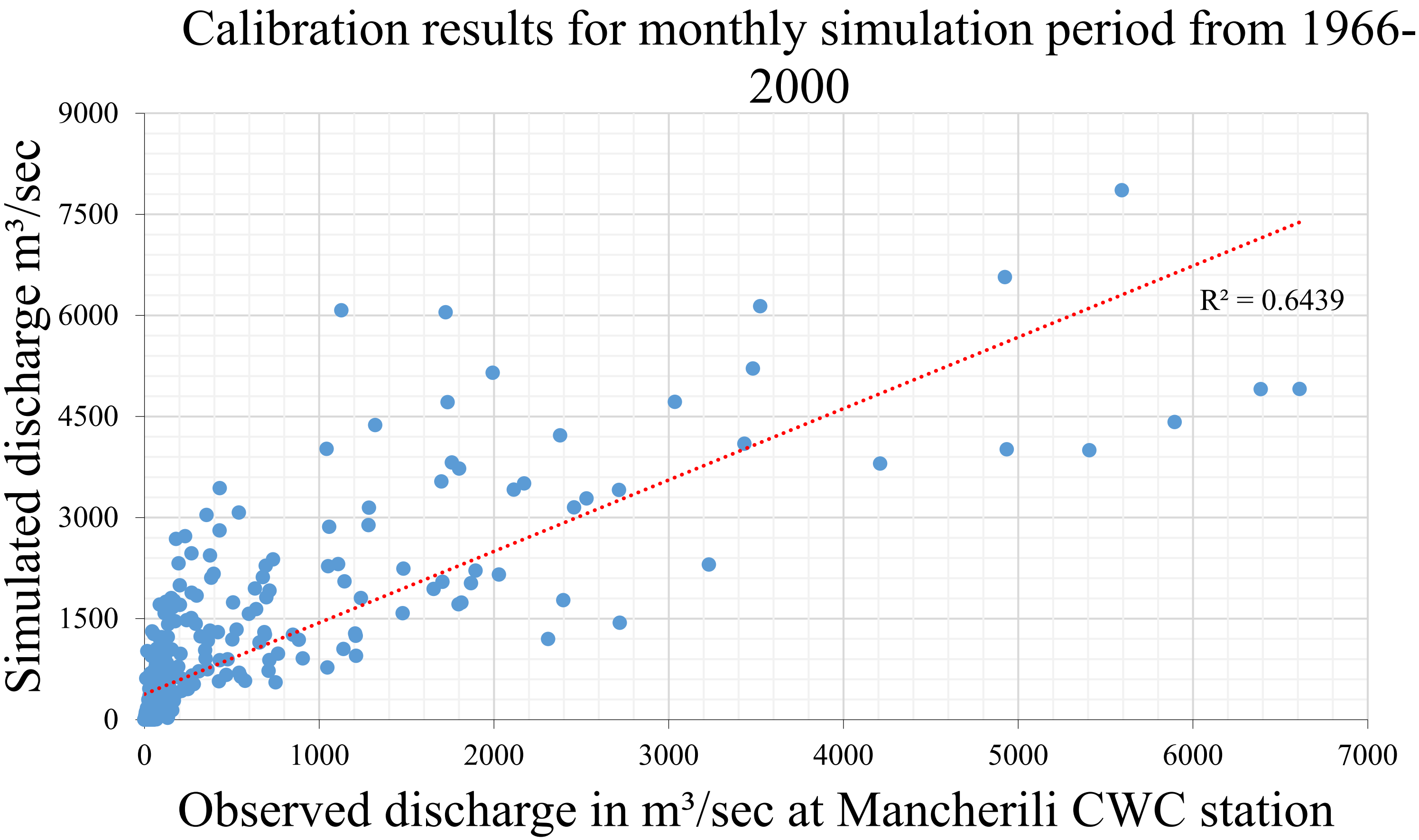
Annual mean water yield(mm) per pixel from (1950-2000)

Calibration and validation of SWAT outputs

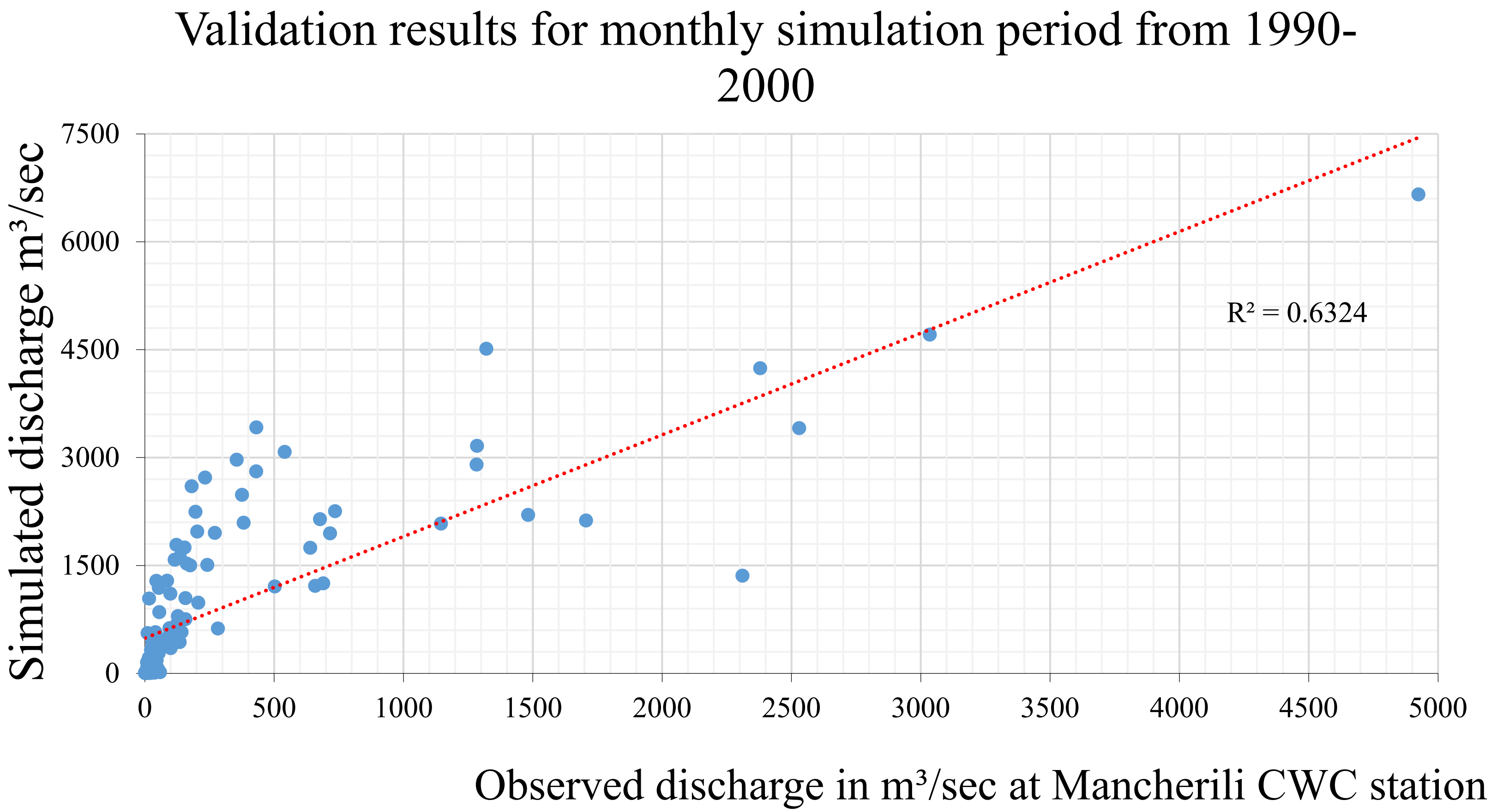
- The SWAT-CUP software module SUFI2 was used to analyse the sensitivity, calibration and validation of the model.
- The calibration was performed for downstream observed discharge location, Mancherli which is CWC operated gauge station.
- Some of sensitive parameters and there range with fitted values are listed below

Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	-0.09765	-0.1	-0.09
2:V__ALPHA_BF.gw	0.41575	0.4	0.75
3:A__GW_DELAY.gw	107	-50	150
4:A__GWQMN.gw	13.25	-100	50
5:V__ESCO.bsn	0.2705	0.2	0.5
6:V__GW_REVAP.gw	0.1967	0.14	0.2
7:R__SOL_AWC(..).sol	0.3355	0.1	0.4
8:R__SOL_K(..).sol	0.3525	-0.1	0.4
9:V__EPCO.hru	0.274	0	0.4
10:V__SURLAG.bsn	8.48	5	13
11:A__RCHRG_DP.gw	0.0115	0	0.1

Calibration using observed discharge



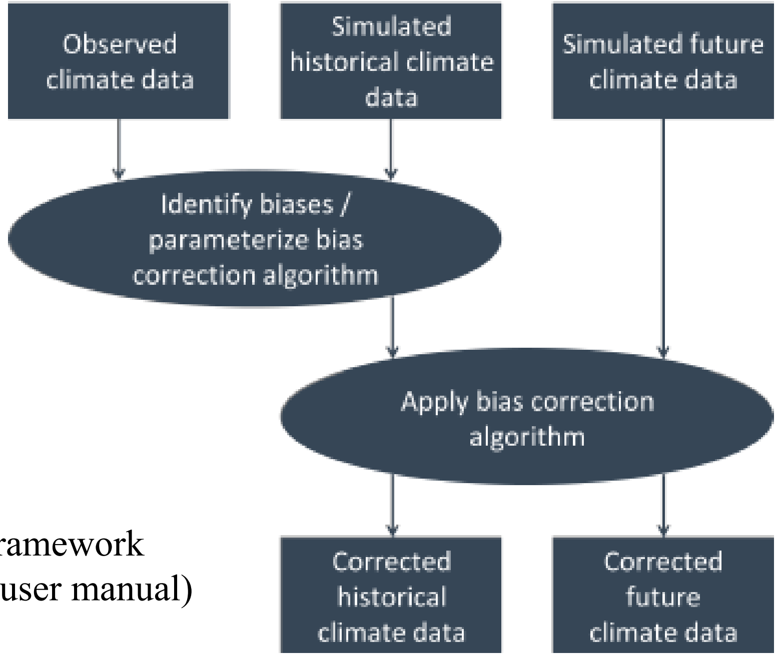
Validation



Validation results for monthly simulation period from 1990-2000
Simulated discharge m³/sec
7500
6000
4500
3000
1500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
R² = 0.6324
Observed discharge in m³/sec at Mancherili CWC station

Bias correction for future climate data

- CMhyd(Climate Model data for hydrologic modeling) tool was used to bias correction of GCM models (CNRM).
- CMIP5(South asia) climate projection data was used for entire Godavari basin
- Pr ,tmax and tmin variables were considered for historical time period of 1960-2000, and future data(RCP8.5,RCP4.5) for 2009-2040
- Observed Precipitation and Temperature data (Pr, Tmax and Tmin) collected from IMD 0.25°× 0.25° grid resolution from 1960-2000.

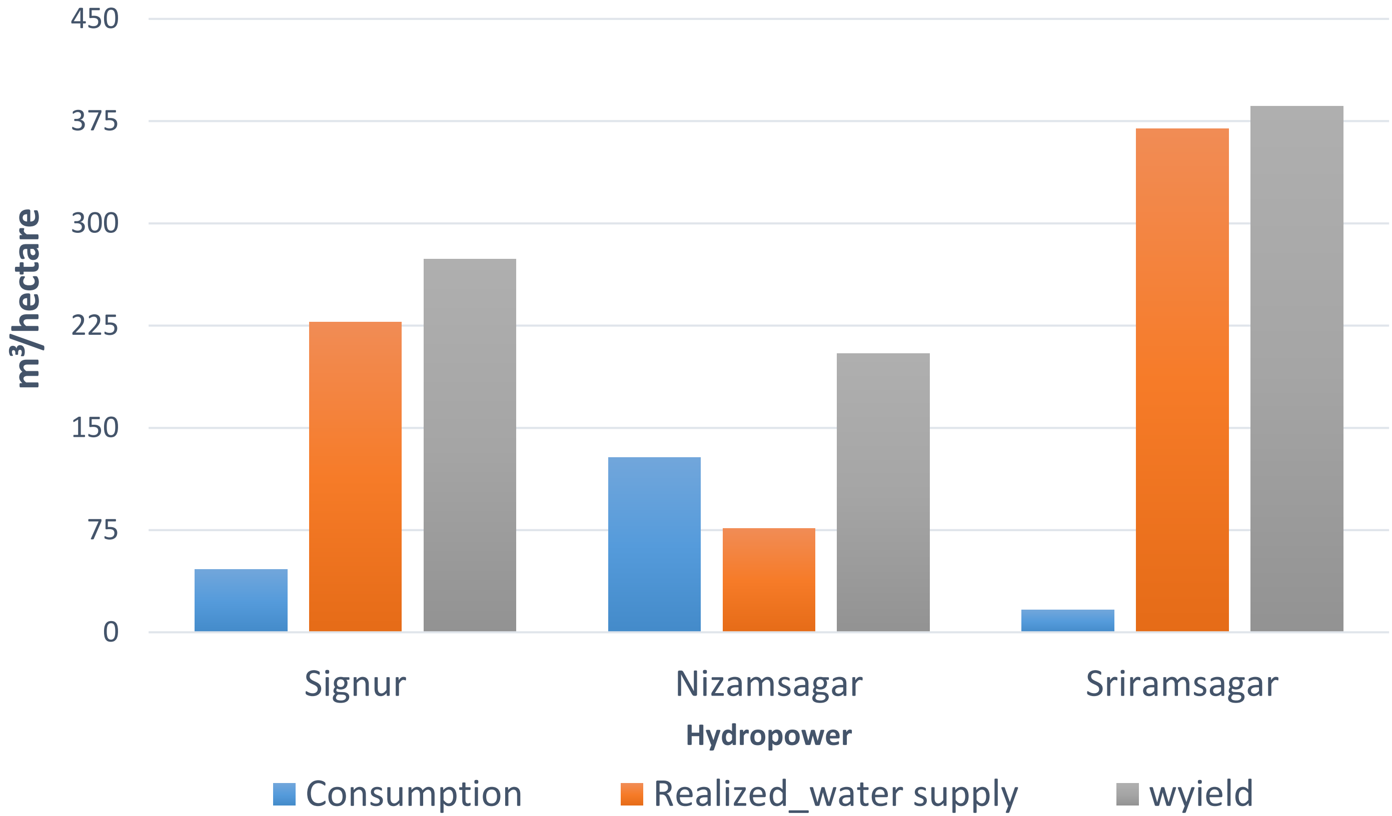


Bias correction framework
(Source: Cmhyd user manual)

Simulated hydrological variables for present and future scenario

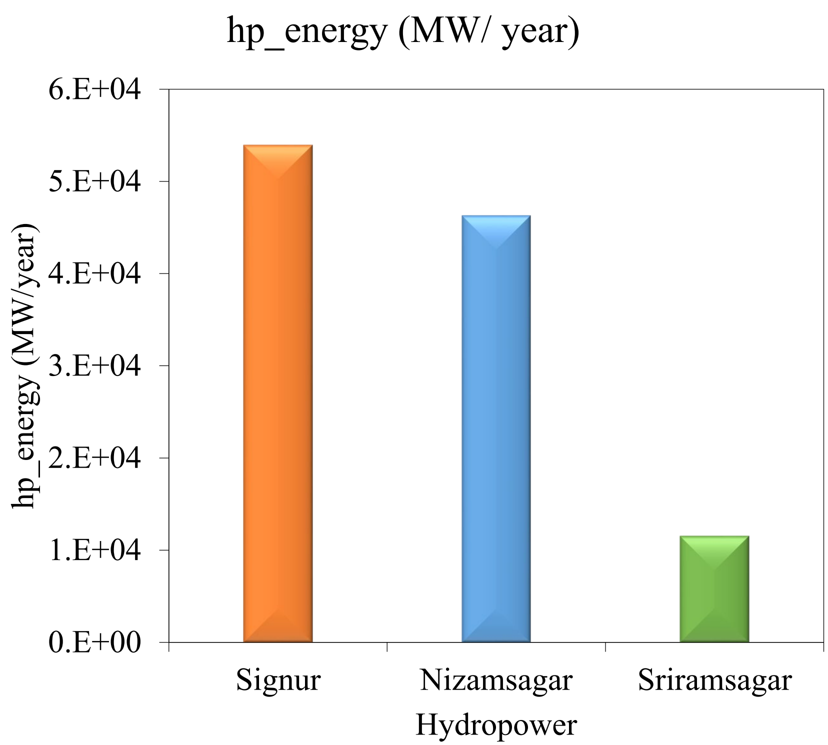
Variables	Present scenario(1964-2000)	Future scenario RCP8.5	Future scenario RCP4.5	% of change 8.5	% of change 4.5
Precipitation(mm)	1242.5	978.6	796.2	2.639	4.463
Total water yield (mm)	728	418.73	384.44	3.0927	3.4356
Organic N(kg/hectare)	6.603	2.884	2.458	0.03719	0.04145
Organic P(kg/hectare)	0.814	0.355	0.321	0.00459	0.00493
Surface Runoff(mm)	386.76	141.34	120.75	2.4542	2.6601
ET(mm)	481.5	531.9	423.5	-0.504	0.58
PET(mm)	1704.4	1361.6	1175.2	3.428	5.292

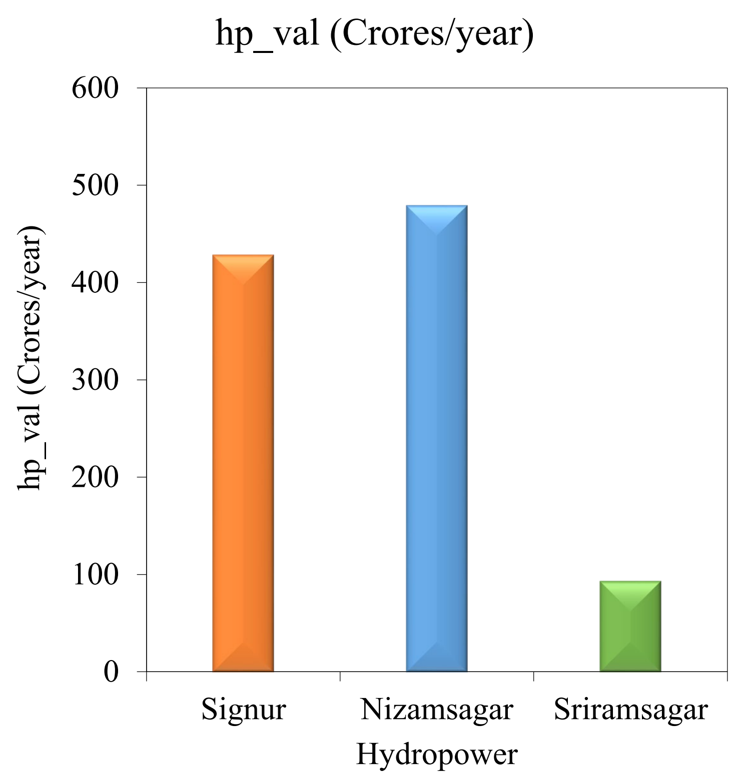
Water scarcity model results



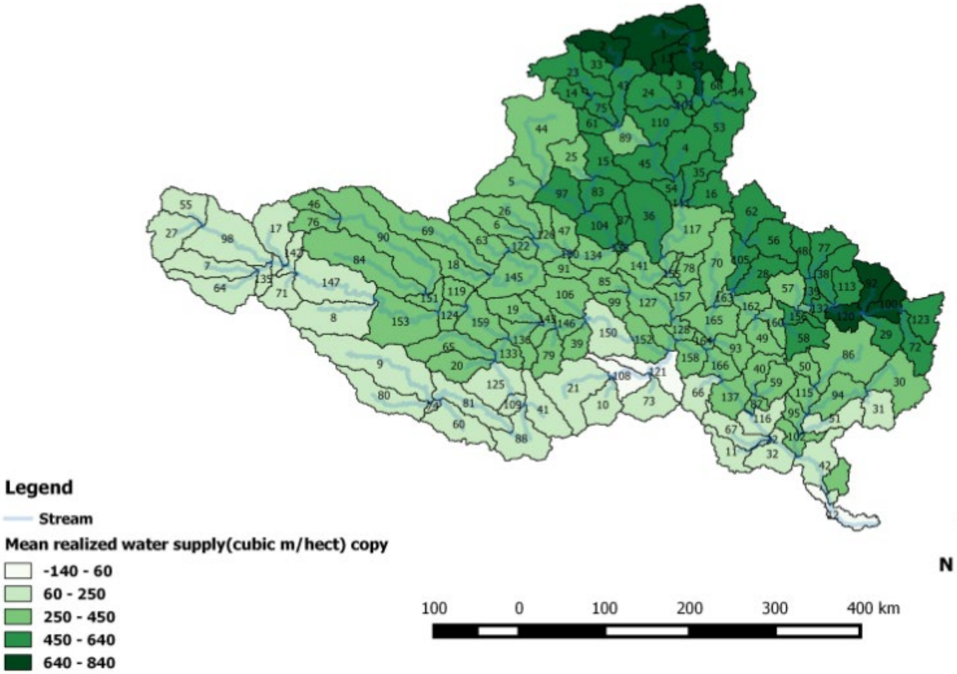
Hydropower valuation results

Hydropower	AET_mm	PET_mm	Consumption(m³/hec)	hp_energy(MW/year)	hp_val(Cr/year)	Realized_water supply(m³/hectare)	wyield(m³/hectare)
Signur	450.30	486.95	46.122661	53908.32	428.52	227.56	273.68
Nizamsagar	433.11	471.25	128.15703	46280.81	478.98	76.33	204.49
Sriramsagar	739.23	810.08	16.516353	11500.43	92.81	369.58	386.09

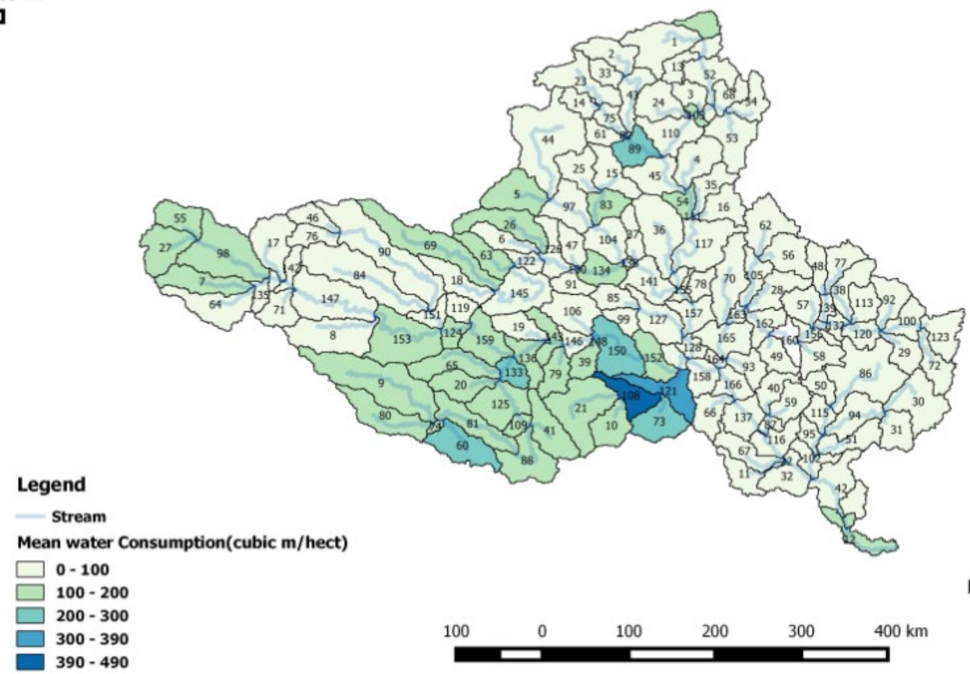


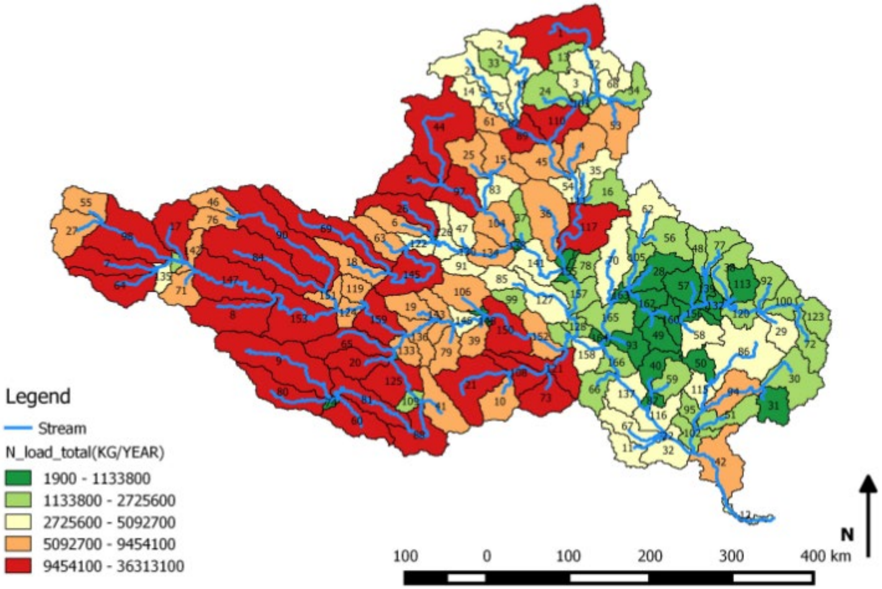


Mean realized water(m^3/hectare)

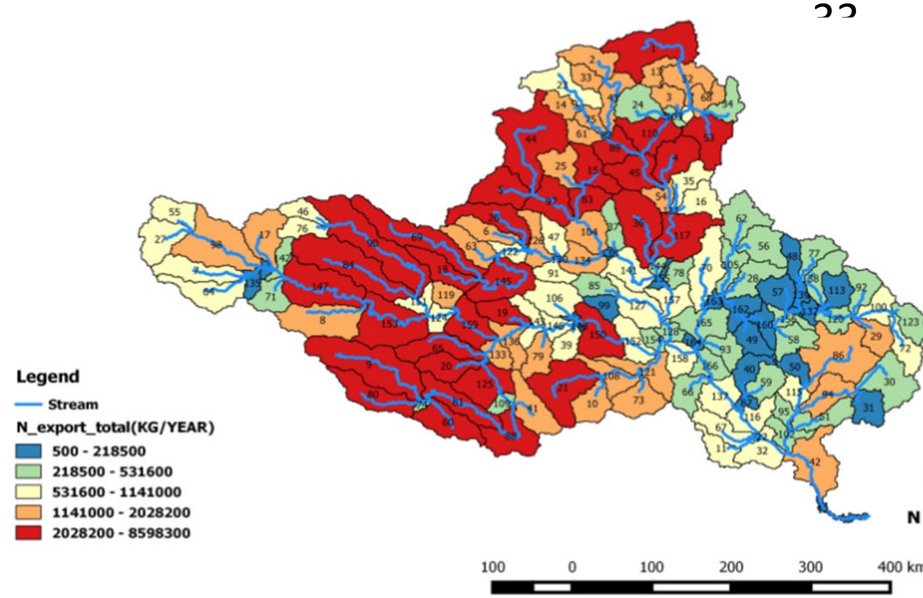


Mean water consumption (m^3/hectare)

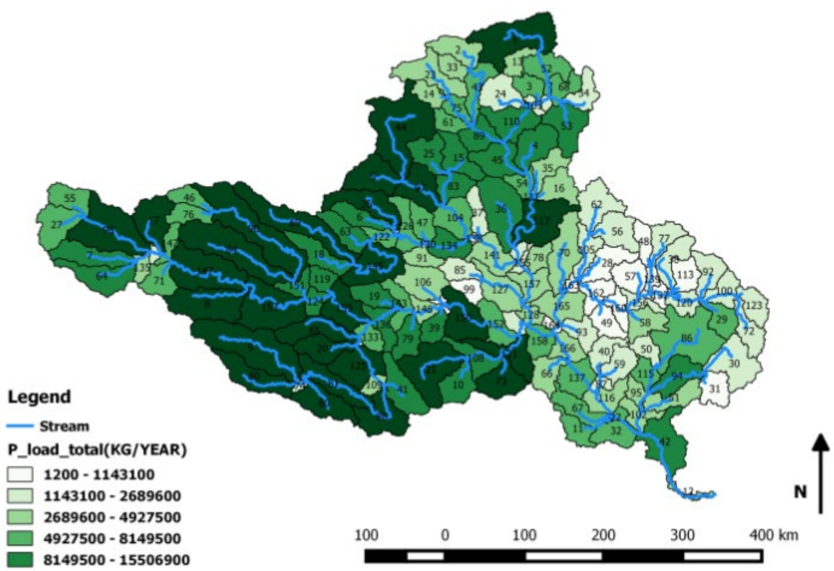




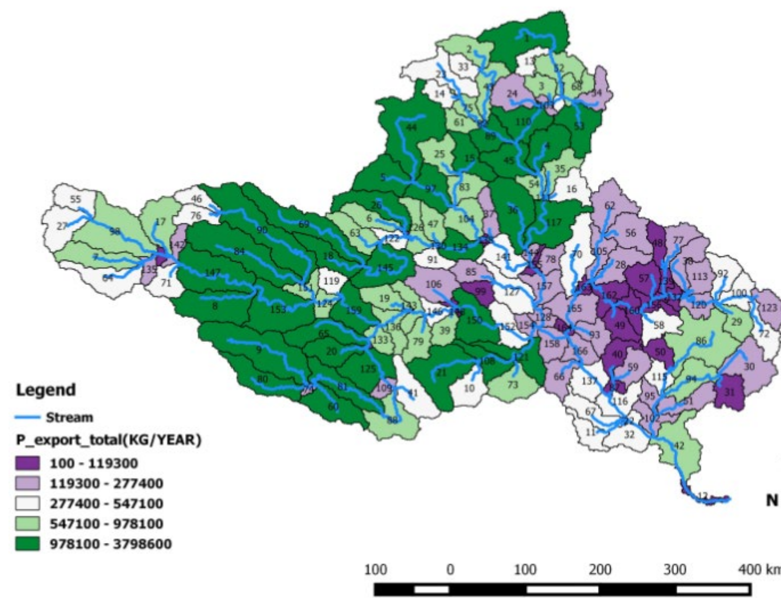
Total Nitrogen loading(kg/year)



Total Nitrogen Export(kg/year)

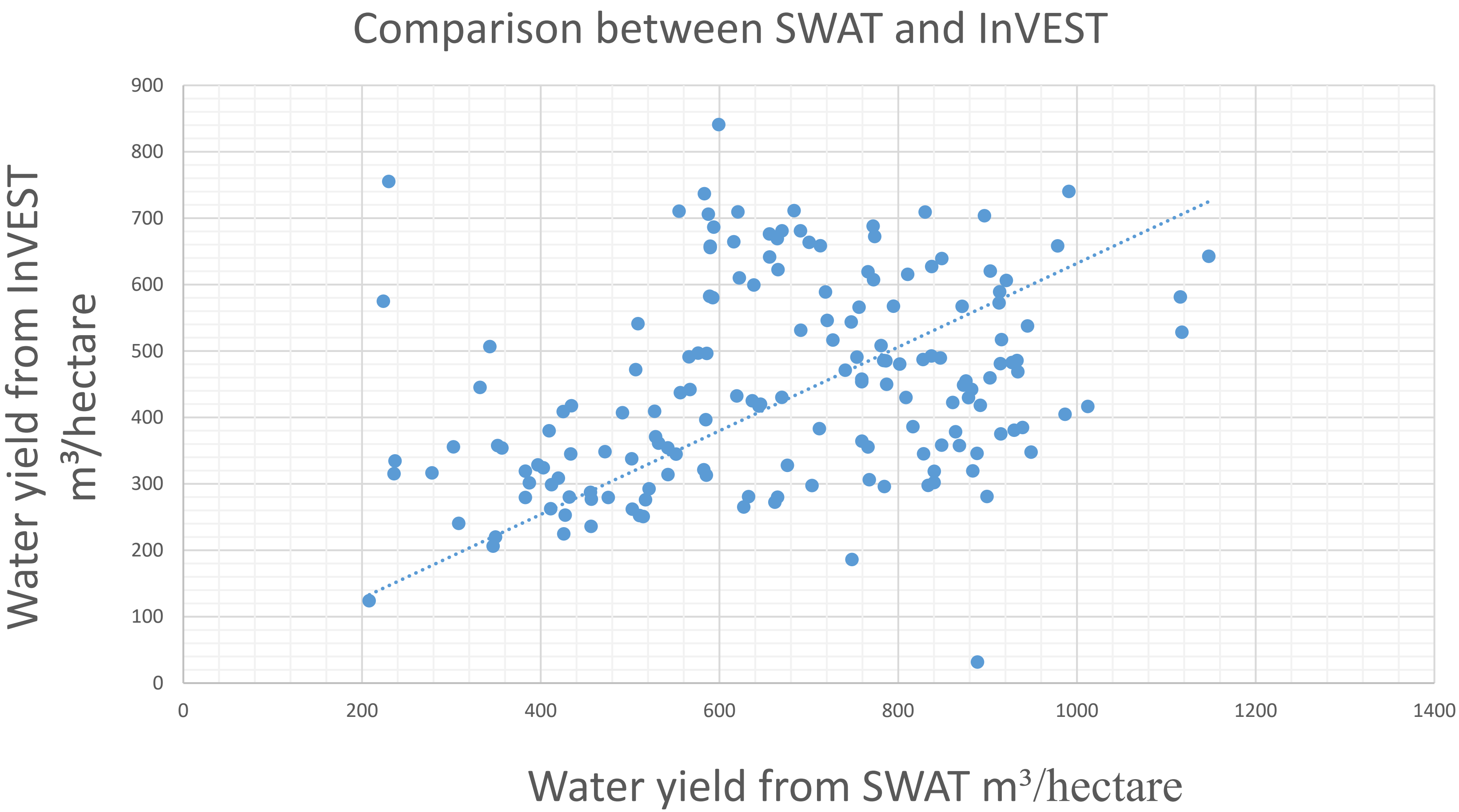


Total Phosphorous loading(kg/year)



Total Phosphorous export(kg/year)

Comparison of annual average water yield b/n SWAT and InVEST



Conclusions

- Water yield being most commonly evaluated hydrological output, in this study we have attempted to use it to value few hydropower production in the Basin.
- From the hydropower valuation, it is noted that even oldest and large hydropower station(Sriramsagar) will produce less energy and value compared to Signur.
- Sriramsagar despite producing highest water yield among other plants, is valued lowest (lifetime of the reservoir is least).
- With number of limitations in the hydropower model, it can be still be significant rather for evaluating how and where changes in a watershed may affect hydropower production for reservoir systems.

Conclusions

- Upstream part of Godavari contributed highest nutrient concentration and export. This clearly indicated intense agriculture and use of fertilizers in the area.

- Eastern part of Godavari was found to be less prone to nutrient loading, N and P export. With no hydropower production and obstruction of flow, it will deemed to be most valuable in terms of ecosystem services.

- Hydrological variables were predicted for future climate scenarios, with precipitation showing decrease of 2.6% & 4.4% for RCP8.5 and 4.5 scenarios.

- SWAT and InVEST simulates different water yields so water related ecosystem services may vary.

THANK YOU

"Lets Take Action, Before its Too Late"

Any Questions ????

NDR model limitations

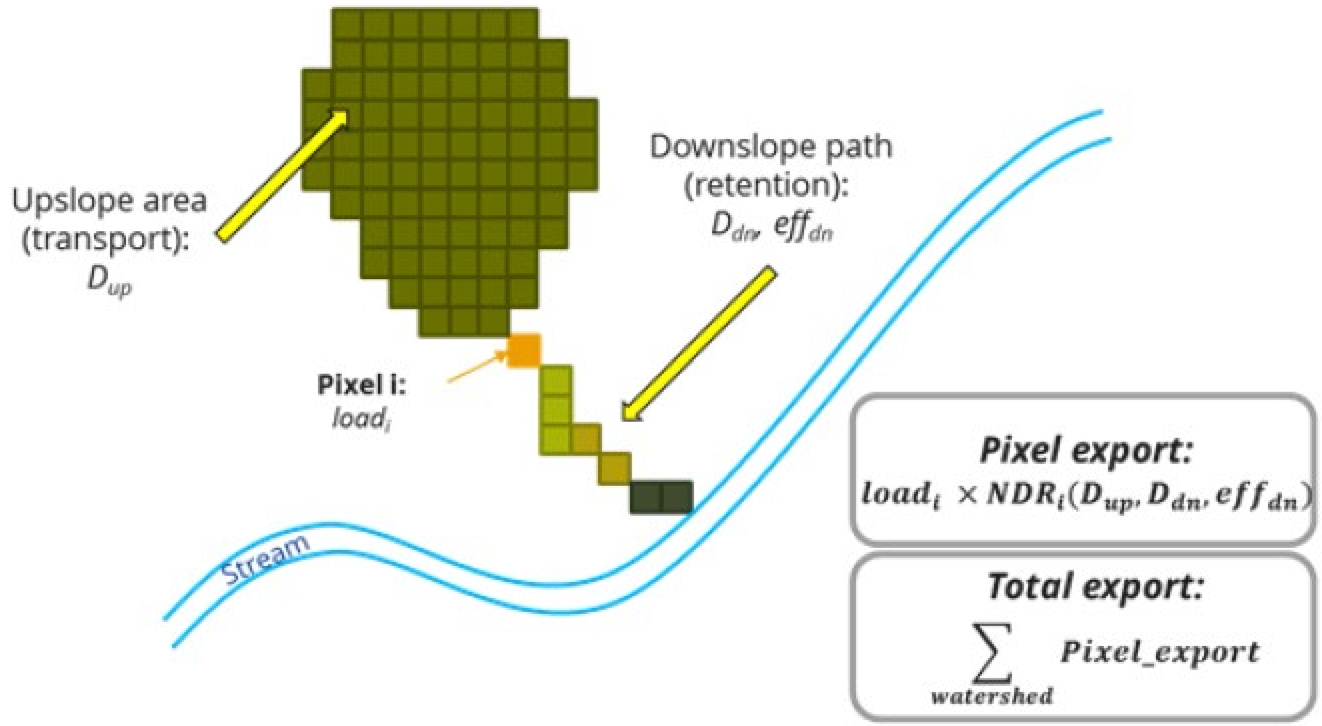
- Outputs generally show a **high sensitivity** to inputs. Which means errors in the **empirical load parameter** values will have a large effect on predictions.

- Factors affecting **retention efficiency** (like slope or intra-annual variability) are averaged.

- The values implicitly incorporate information about the dominant nutrient dynamics, influenced by climate and soils.

- The effect of grid resolution on the NDR formulation has not been well studied.

Nutrient delivery ratio(NDR) model



Conceptual representation of the NDR model. Each pixel i is characterized by its nutrient load, loadi, and its nutrient delivery ratio (NDR), which is a function of the upslope area, and downslope flow path.

Source: InVEST User's Guide. The Natural Capital Project

Surface NDR

- The surface NDR is the product of a delivery factor, representing the ability of downstream pixels to transport nutrient without retention, and a topographic index, representing the position on the landscape. For a pixel i:

$$NDR_i = NDR_{0,i}\left(1+\exp\left(\frac{IC_i - IC_0}{k}\right)\right)^{-1}$$