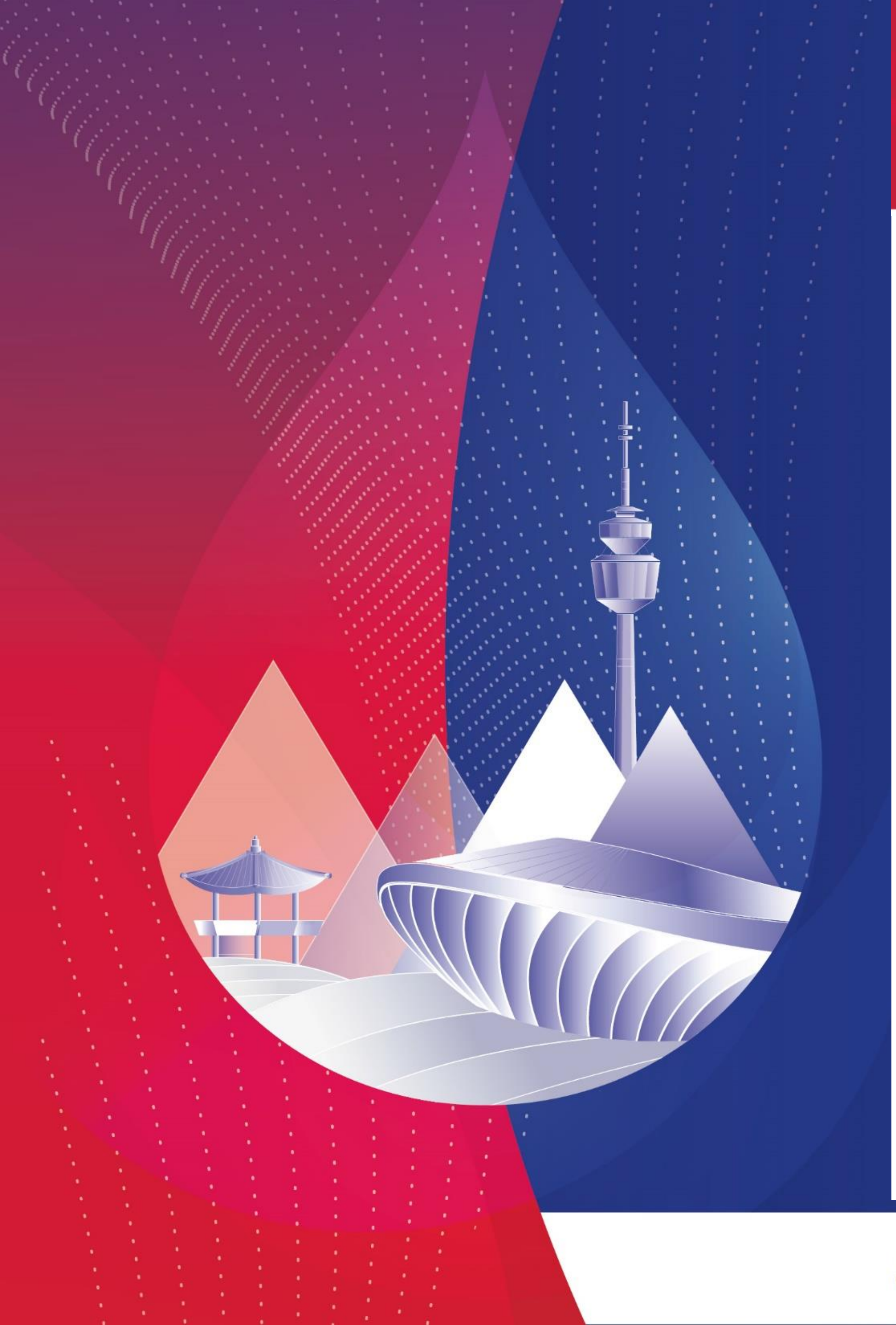

IWRA's XVII
WORLD WATER CONGRESS
29 Nov - 3 Dec, 2021
EXCO Daegu, Republic of Korea

Assessment of Ecosystem Services under Land use and Climate Change

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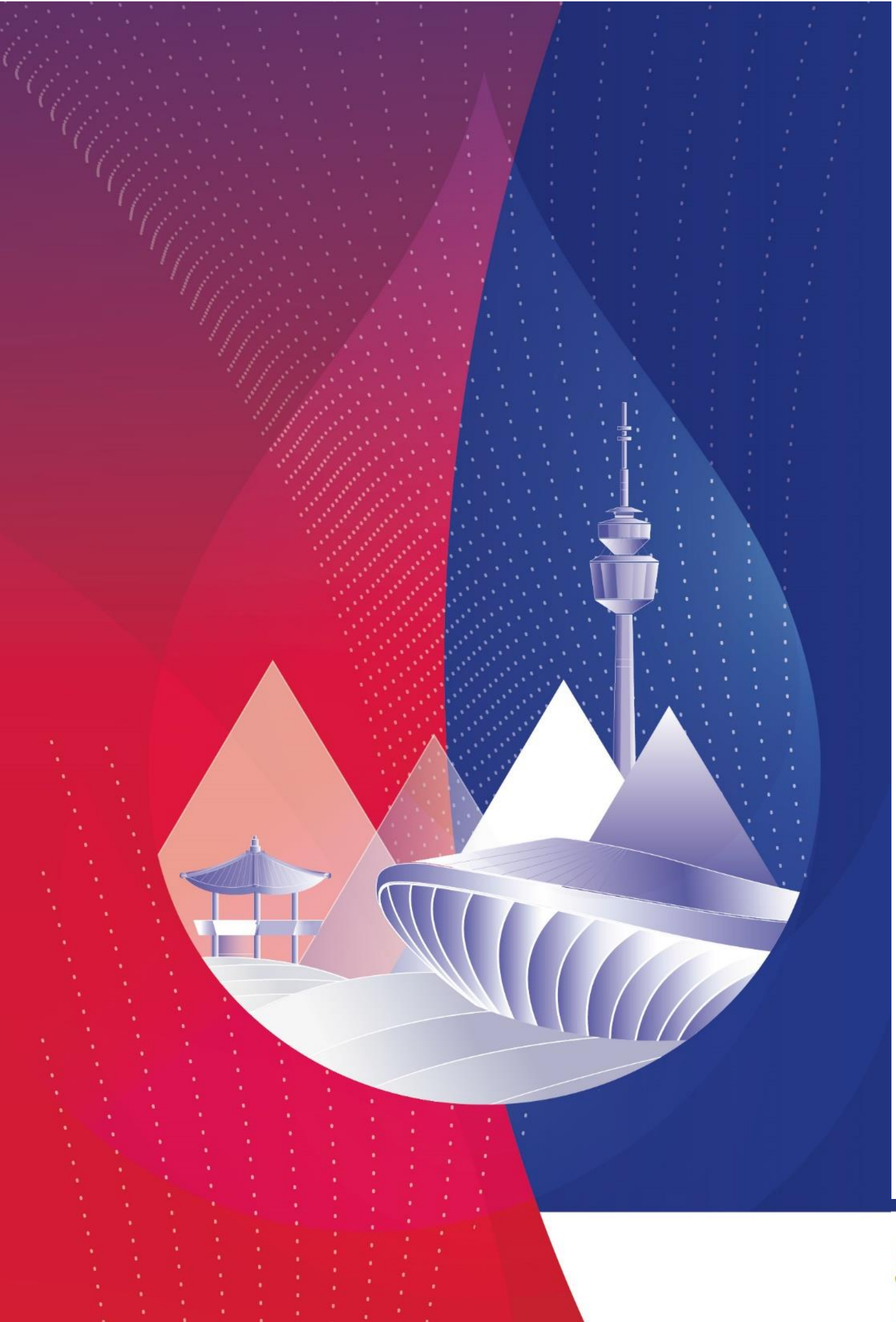

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1. Introduction

1.1 Ecosystem services (ES)

The goods and services provided by nature that contribute to the well-being of humans.

Millennium Ecosystem Assessment (MEA) report, 2005 -Milestone in the field

Human actions are depleting Earth's natural capital.
Ability of planet's ecosystem to sustain future generations cannot be taken for granted.

Significance is high on developing nations like Nepal as livelihood of people is highly dependent on these services.

Classification of Ecosystem Services

1. PROVISIONING SERVICES
Products from ecosystem.
Food, timber, freshwater etc.

2. REGULATING SERVICES
Benefits from regulation of ecosystem processes.
Climate regulation, flood regulation etc.

3. CULTURAL SERVICES
Nonmaterial benefits from ecosystems.
Recreation, spiritual, asthetic etc.

4. SUPPORTING SERVICES
Underpinning services that enable other services to function.
Soil formation, nutrient cycling.

Issues of global concern

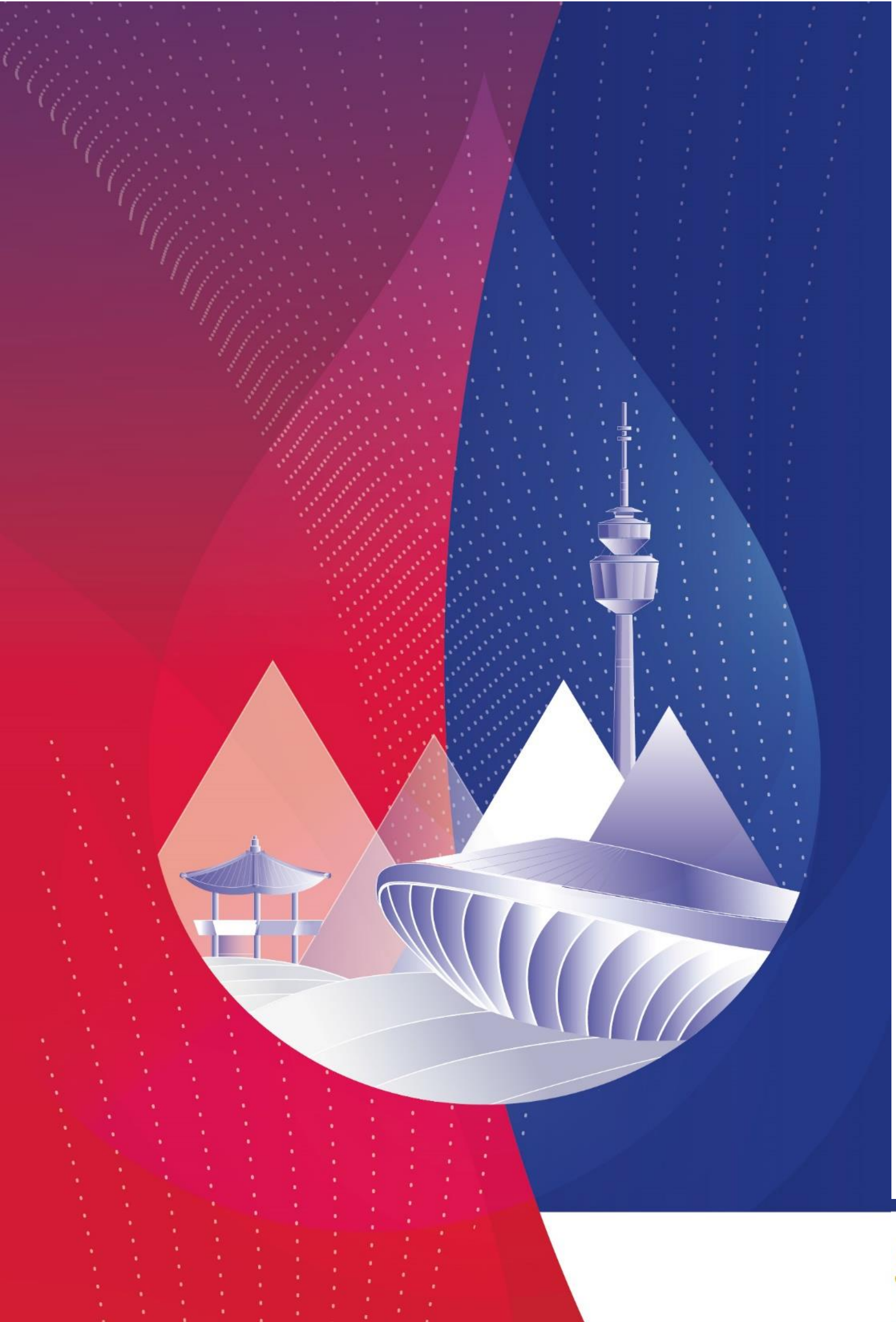
1.2 Objectives of the Study

Why was this study started??

- Developing country are at high risk of ES loss
- Most study in Nepal is focused on small areas and especially on community forest and drinking water.
- Payment of Ecosystem Services – primarily focused on Carbon storage and water provisions.
- Basin wide study – land use and land cover impacts study – are not highlighted.
- Basin wide study – promotes sustainable land use and ensures protection of ES services.

Objectives of the Study

- Water Yield Estimation
- Soil loss Estimation
- Carbon storage Estimation
- Nitrogen export Estimation
- Comparison of ES with land use and land cover change.



2. Methodology

2.1 Study Area

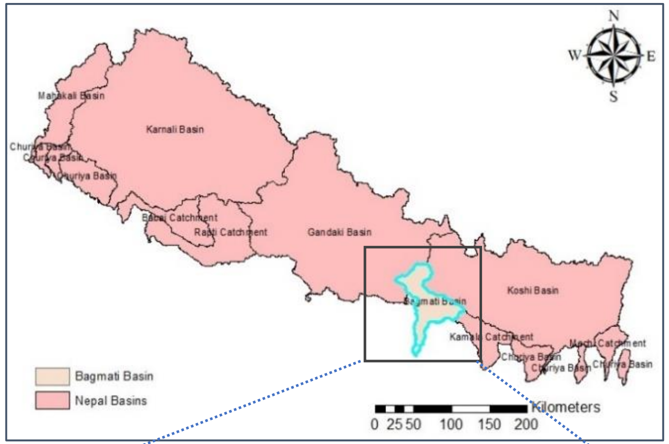
Basin name: Bagmati Basin

Area of Basin : 3,750 sq. km

Area of basin considered on the study : 2,768.97 km^2

Elevation: Varies from 78m to as high as 2943 m from sea level.

Figure: ***Location of the Study Basin***



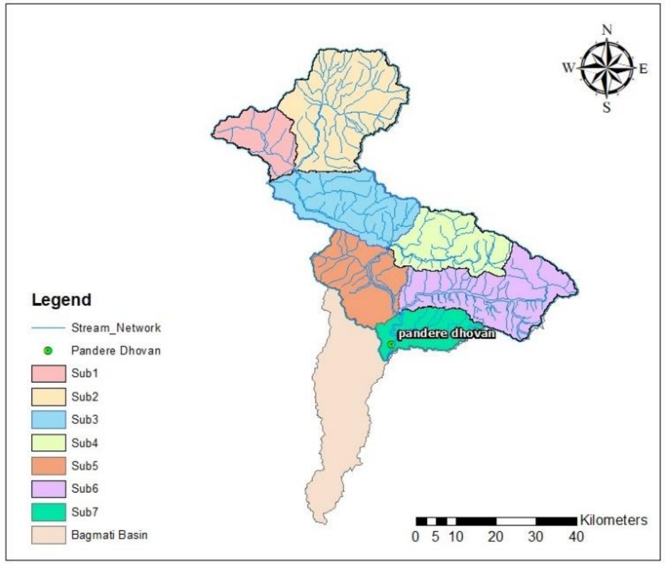


Figure: ***Sub-watershed Used in the Study***

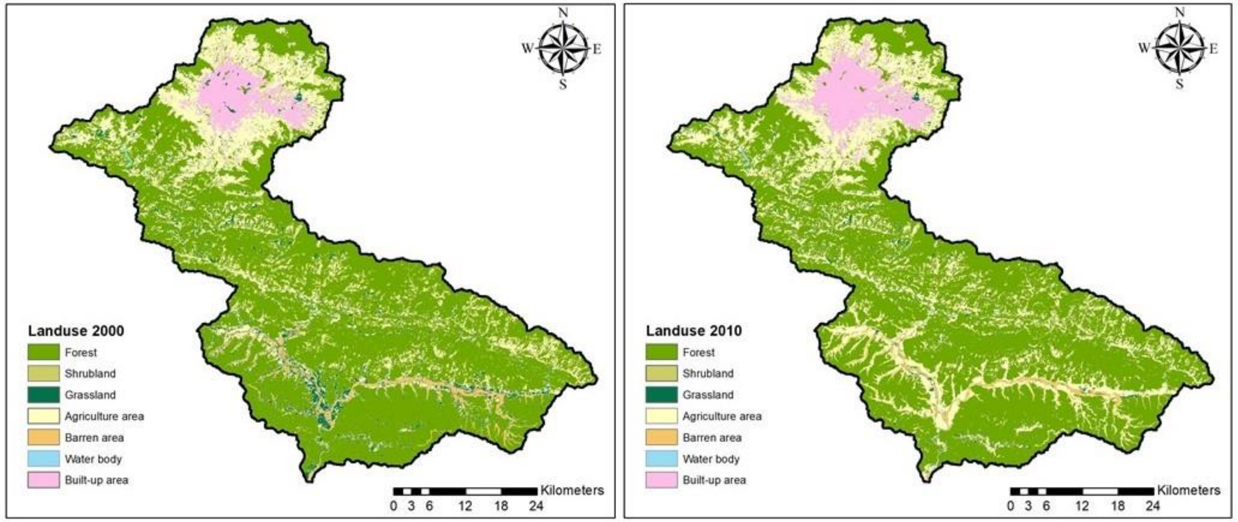
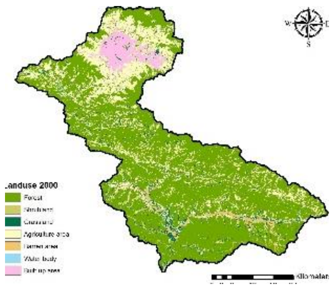


Figure: ***LULC map 2000 and 2010***

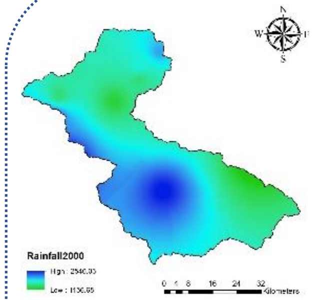
2.2 Data Sources



Land use and Land cover

- Obtained from the ICIMOD Nepal Geospatial Portal .
- Prepared using public domain landsat TM data
- Consists 7 attributes : Forest, grassland, shrubland, built-up agriculture, waterbody and barren land

Years: 2000 & 2010



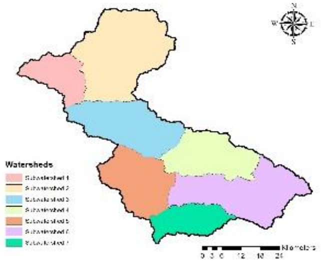
Precipitation Data

- Purchased from the DHM, Nepal.
- Rainfall map prepared using IDW method in Arc GIS.
- Average rainfall of the basin 1600mm.

Years: 1987-2016

Digital Elevation Map (DEM)

- Obtained from the National Agricultural Research Council, NARC Nepal.
- Resolution: 20m
- Elevation varies from 82.5 m to 2943.68m



Watersheds and Subwatersheds

- Based on DEM, generated using ArcSWAT.
- Seven sub-watersheds.

2.2 Data Sources

Biophysical table

- Source of data- Various published literatures and InVEST User guidelines
- Kc- Plant evapotranspiration coefficient
- Root depth- maximum root depth(mm) for LULC types
- Carbon pools- mg per ha
- Load_n / Load_p – nutrient loading (kg per ha per year)

Table 1 Biophysical attributes used for the InVEST models

LULC_desc	Forest	Shrubland	Grassland	Agriculture land	Barren Area	Water body	Builtup area
lucode	1	2	3	4	5	6	8
Kc	1	0.398	0.65	0.65	0.5	1	0.3
Rootdepth	7000	2000	2000	1500	500	0	0
LULC_veg	1	1	1	1	0.001	0.001	0.001
C_above	90	5	8	6	3	0	0
C_below	60	3	8	6	2	0	0
C_soil	95	20	25	20	8	0	0
C_dead	29	0	3	2	1	0	0
load_n	1.8	2	4	11	4	0.001	7.25
load_p	0.011	0.011	0.05	3	0.001	0.001	1.1
eff_n	0.8	0.4	0.5	0.25	0.05	0.05	0.05
crit_len_p	30	30	30	30	30	30	30
crit_len_n	30	30	30	30	30	30	30
eff_p	0.8	0.5	0.4	0.25	0.05	0.05	0.05

2.3 Evaluation of Ecosystem Services(ES)

Four ES services :

Water yield (WY) – Regulating Service

Soil Loss - Regulating Service

Carbon storage – Regulating Service

Nutrient delivery – Regulating Service

Mapped based on **LULC maps of 2000 and 2010** AD and corresponding **climate data.**

Soil loss is computed using **RUSLE** & **WY, Carbon, and Nitrogen export** are mapped using **InVEST model .**

(MME) of 12 best **GCMs of CMIP5** under scenario **RCP 4.5 and RCP 8.5**, downscaled by using APCCs' AIMS software is used to create climate data to study the projection of ES in future.

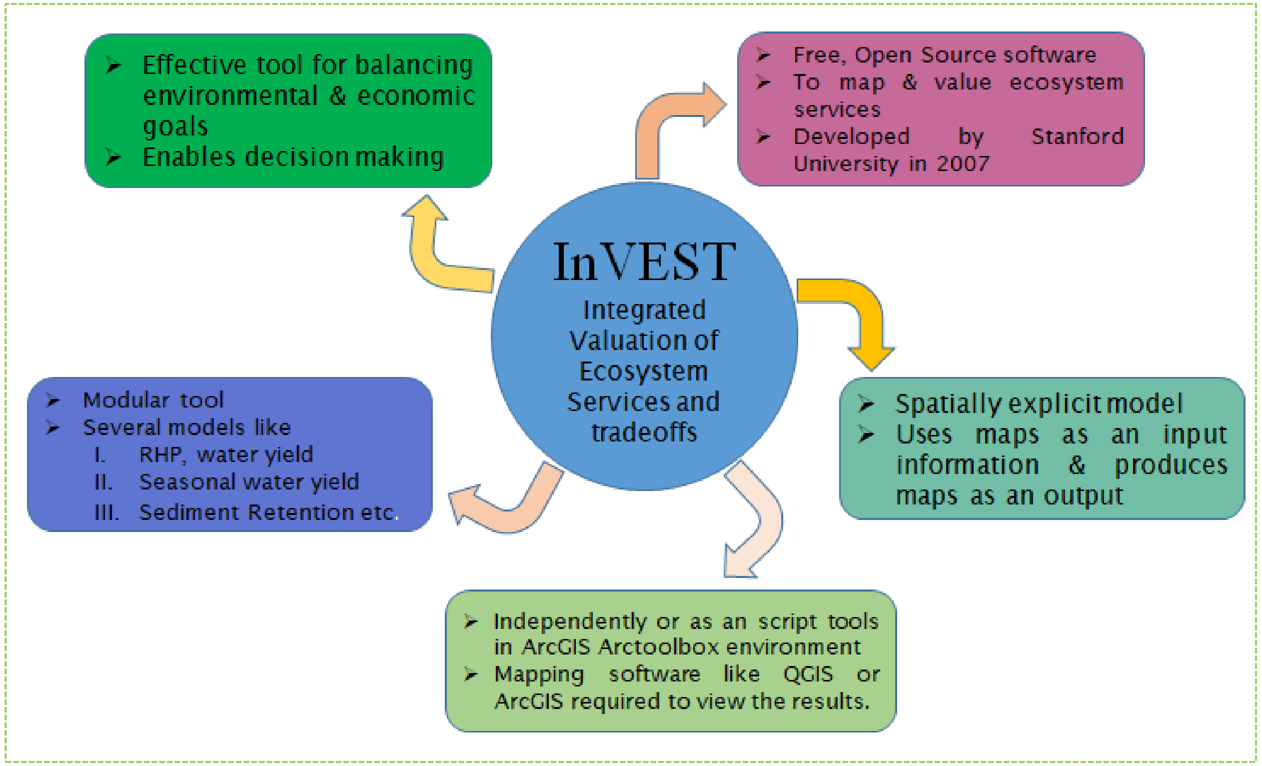


Figure: InVEST ES Tools Overview

2.3.1 Water Yield Model

- Determines the amount of water running off each pixel as the precipitation minus the fraction of the water that undergoes evapotranspiration.
- Based on the Budyko curve and annual average precipitation.
- $Y(x) = (1 - \frac{AET(x)}{P(x)}) * \mathrm{P(x)}$

Y(x) – Annual water yield for each pixel
AET(x) - the annual actual evapotranspiration
P(x) - annual precipitation on pixel x.

$$\frac{AET(x)}{P(x)} = 1 + \frac{PET(x)}{P(x)} - \left[1 + \left(\frac{PET(x)}{P(x)}\right)^{\omega}\right]^{1/\omega}$$

$$PET(x) = Kc(l_x) * ET_o(x)$$

$$\omega_{(x)} = Z\frac{AWC(x)}{P(x)} + 1.25$$

- PET(x) is potential evapotranspiration
- $ET_o(x)$ is the reference evapotranspiration from pixel x
- $Kc(l_x)$ is the plant evapotranspiration coefficient
- ω(x) is a non-physical parameter that characterizes the natural climatic-soil properties.
- Z constant defines local precipitation and hydrogeological characteristics of the basin

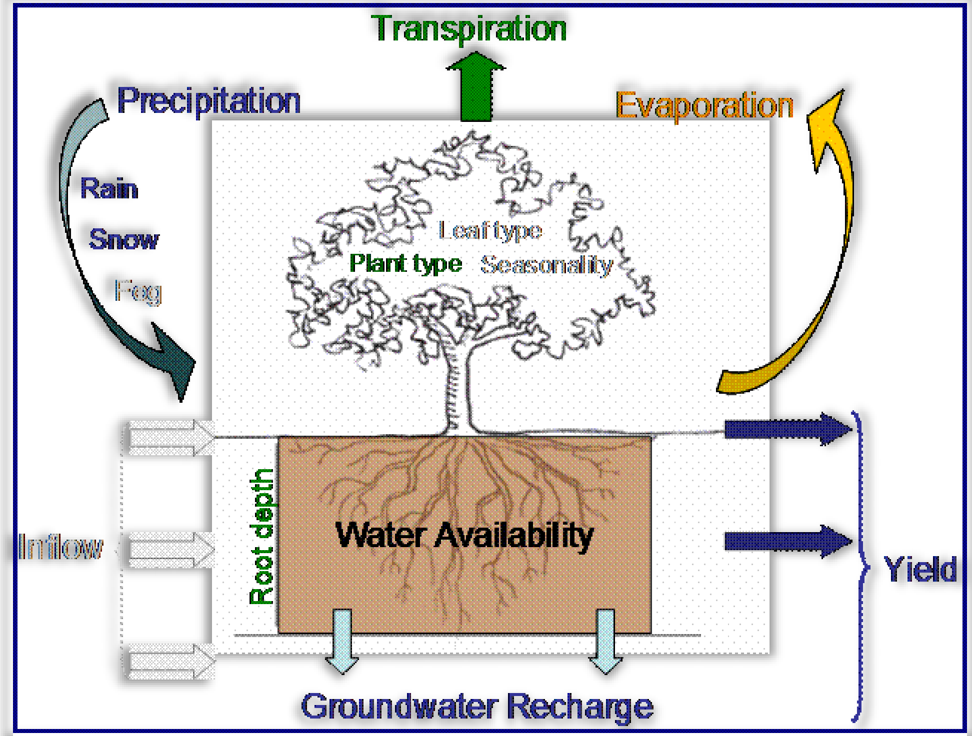


Figure: Conceptual diagram of the simplified water balance method

2.3.1 Water Yield Model

Z parameter is calibrated by comparing the model output with observed streamflow at outlet streamflow gauge station.

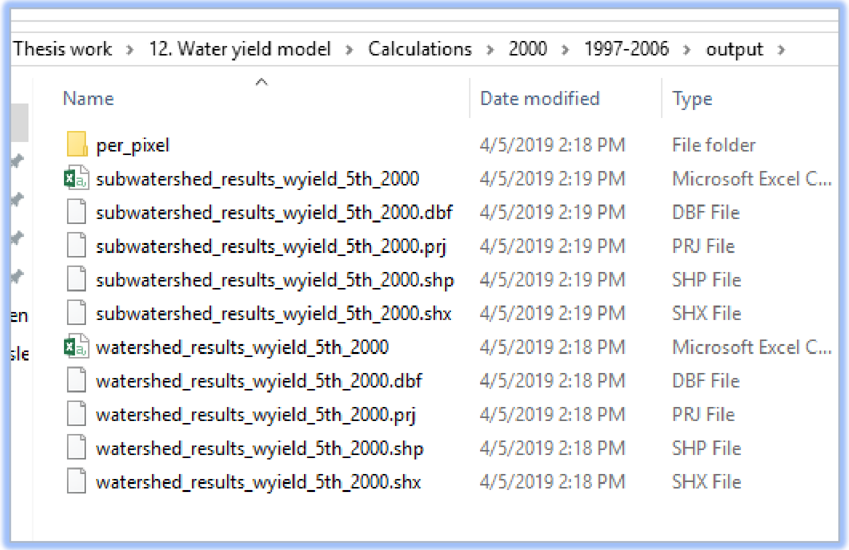


Figure: Output files

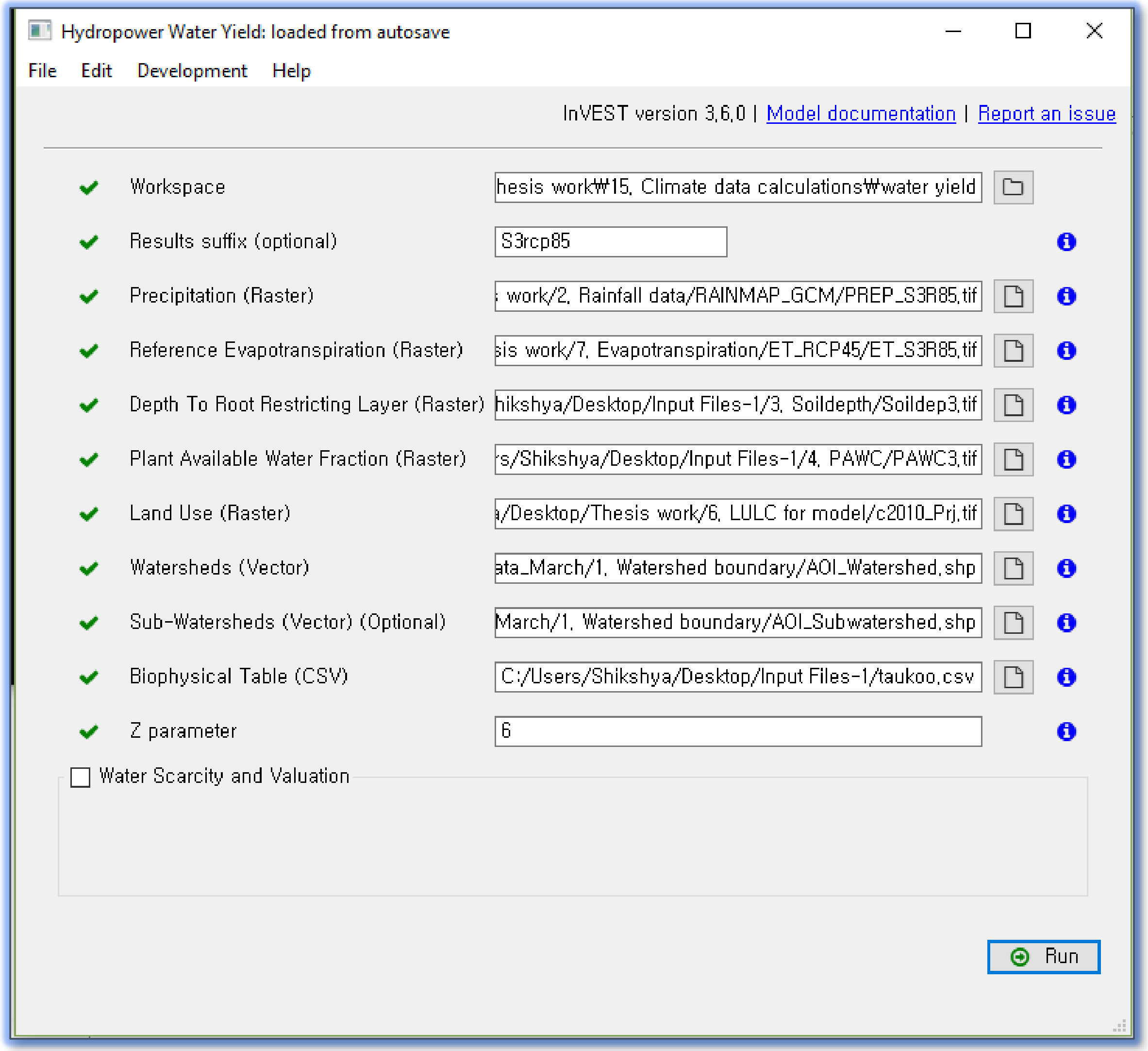


Figure: Model interface

2.3.2 Soil Loss by Revised Universal Soil loss Equation

- RUSLE - Widely used model at large scales
- Well known for data simplicity and its provision of basis for carrying out scenario analysis and taking measures against erosion.
- Uses a combination of geo-physical and land cover factors to estimate the likely annual soil loss from a unit of land.
- The RUSLE equation is as follows:

$$A = R * K * L * S * C * P$$

Where, A= average annual soil loss amount in (Mg or t/ha/yr)

R= Rainfall-runoff erosivity factor (MJ mm/h/ha/yr)

K= Soil erodibility factor

L= slope length factor

S= Slope steepness factor

C= Land cover management factor

P= Support practice factor

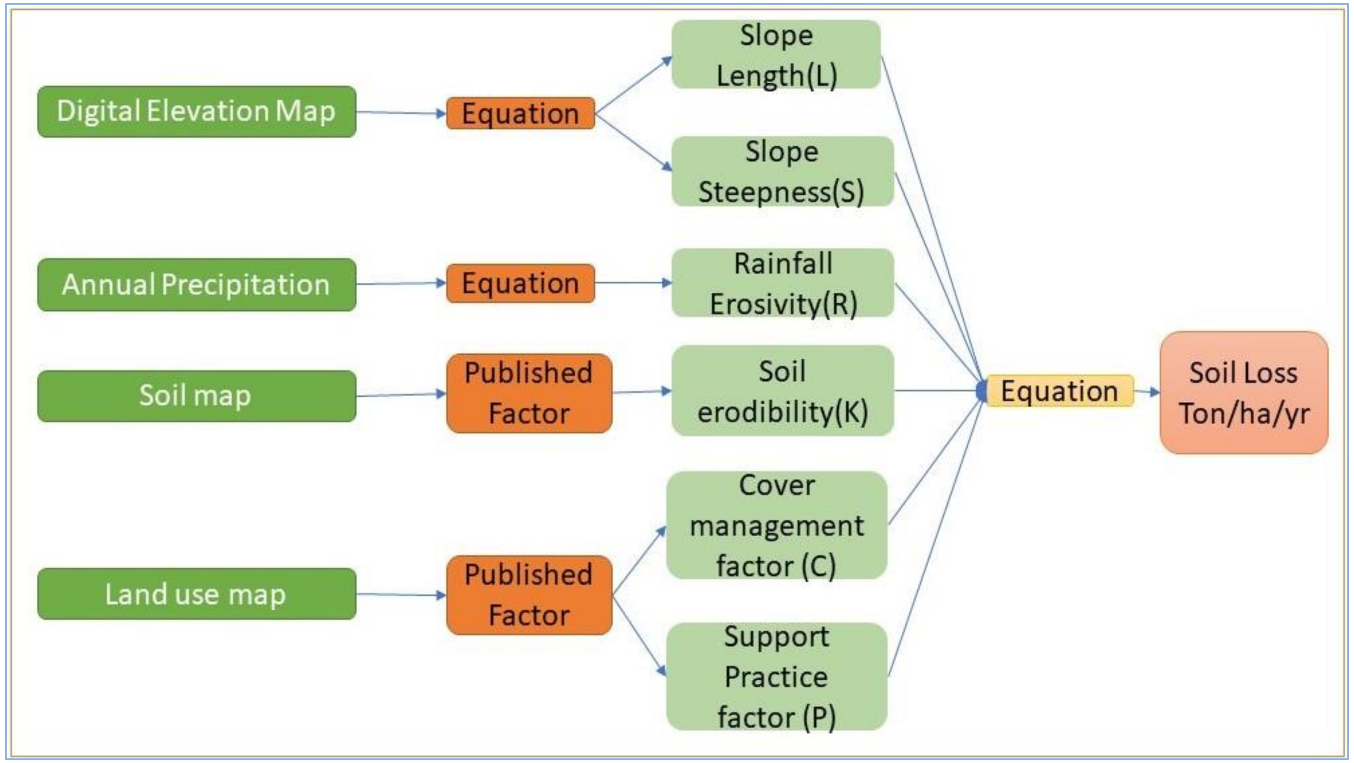


Figure: RUSLE Data Preparation

2.3.3 Carbon Storage and Sequestration Model

- The model maps carbon storage densities to LULC rasters.

- It aggregates the amount of carbon stored on four major carbon pools to produce total amount of carbon storage.

(Carbon pools)

- aboveground biomass,
- belowground biomass,
- soil
- dead organic matter

- $$Value_{seq} = V \frac{sequest(X)}{yr_{fut} - yr\_cur} \sum_{t=0}^{yr_{fut} - yr_{cur} - 1} \frac{1}{(1+\frac{r}{100})^t (1+\frac{c}{100})^t}$$

The output of the model is expressed as million grams per hectare (mg per ha).

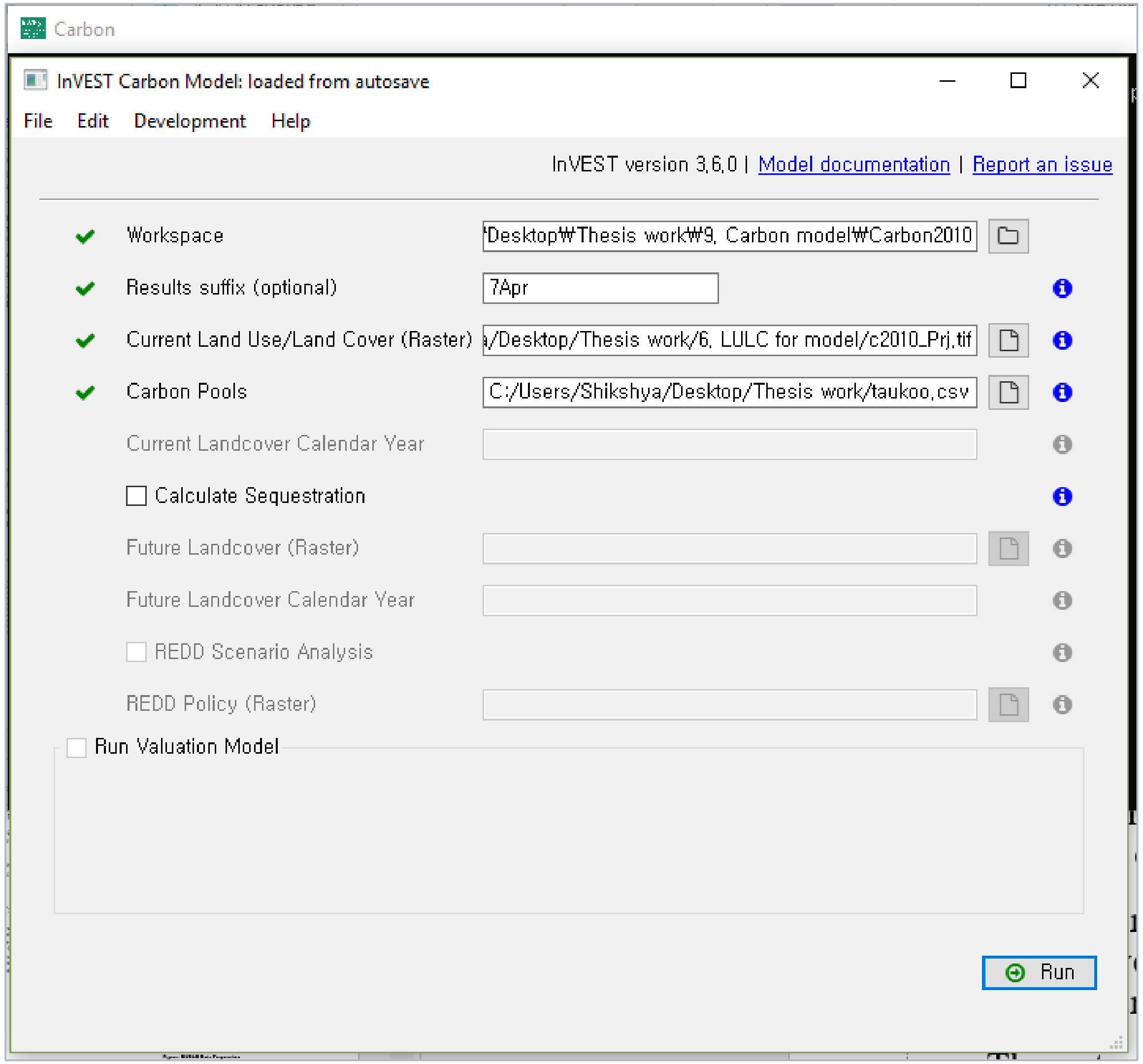


Figure: Carbon Model Interface

2.3.4 Nutrient Delivery Ratio Model

- Uses a simple mass balance approach.
- Describes the movement of a mass of nutrient through space and aims to quantify nutrient export.
- Maps the transport of nutrients from watershed sources to the stream network.
- Sources of nutrients are determined based LULC map & associated loading rates.

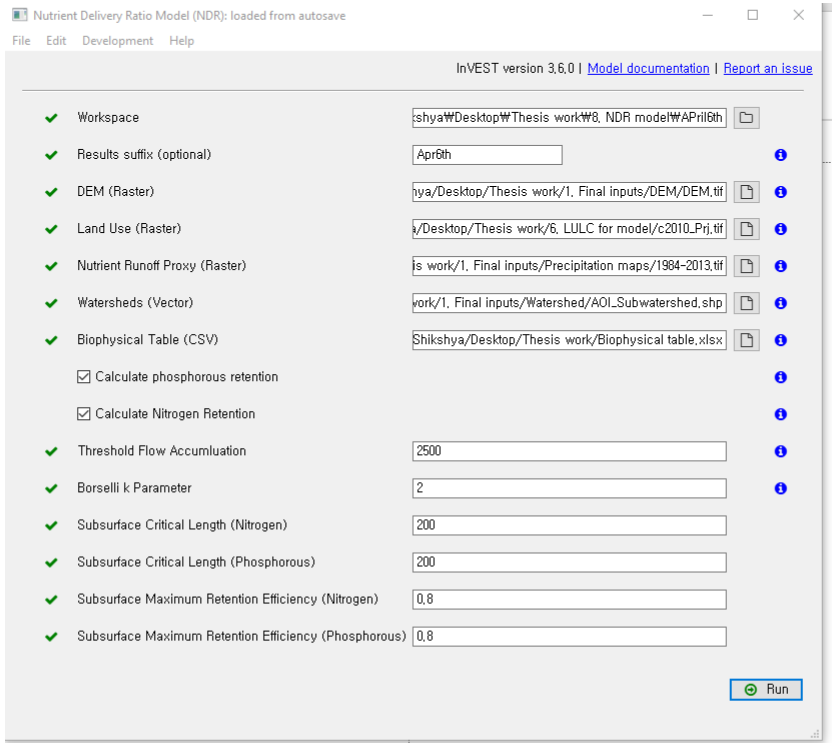


Figure: Model interface

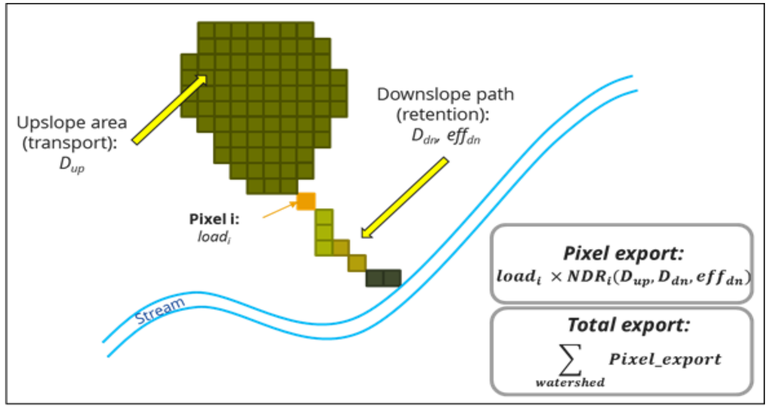


***Figure**: Conceptual representation of the NDR model*

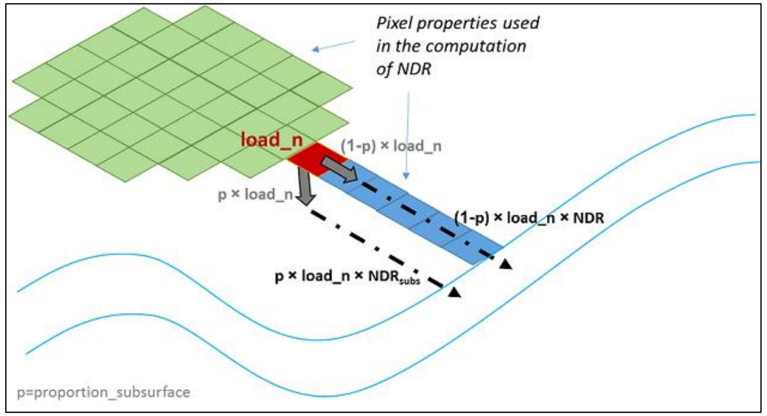


***Figure**: Conceptual representation of nutrient delivery in the model*

2.4 Future Climate Projection

- General Circulation Models (GCMs) - serves as useful basis and they are probably the only kind of tool to predict future climate.

- Have inherent problems due to a coarse resolution - difficulty to capture climatic characteristics at regional or local scales.

- Application of downscaling technique – Statistical and Dynamic Downscaling Technique

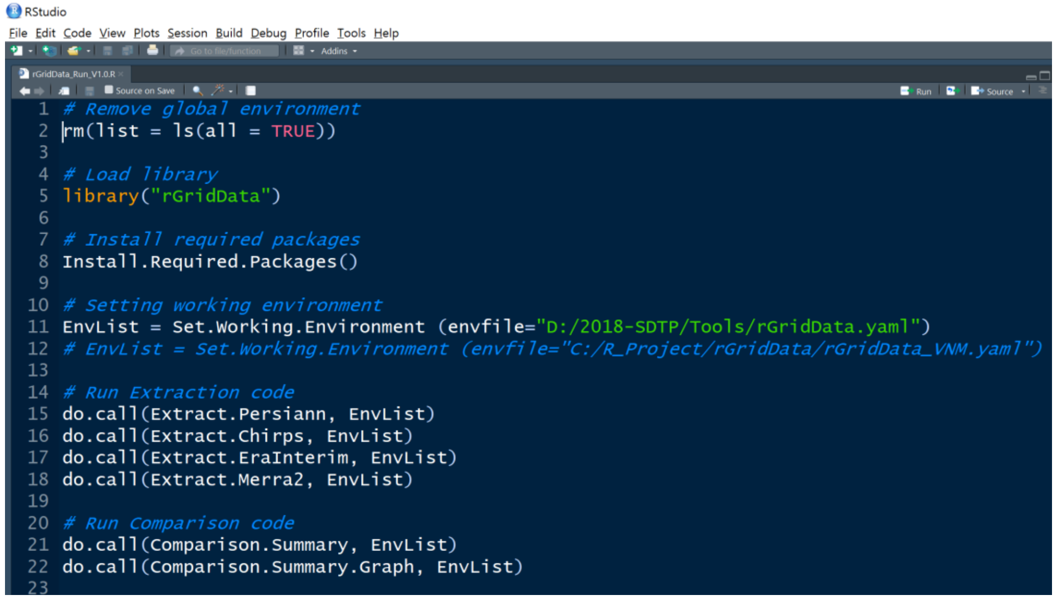
- Bias Correction is required – Quantile mapping method is used.

- Uncertainties among climate models - many studies recommends use of multiple models.

- Ensemble averaging can improve the accuracy of a climate projection by allowing GCM errors to cancel each other out and GCMs that poorly performed to be down weighted.

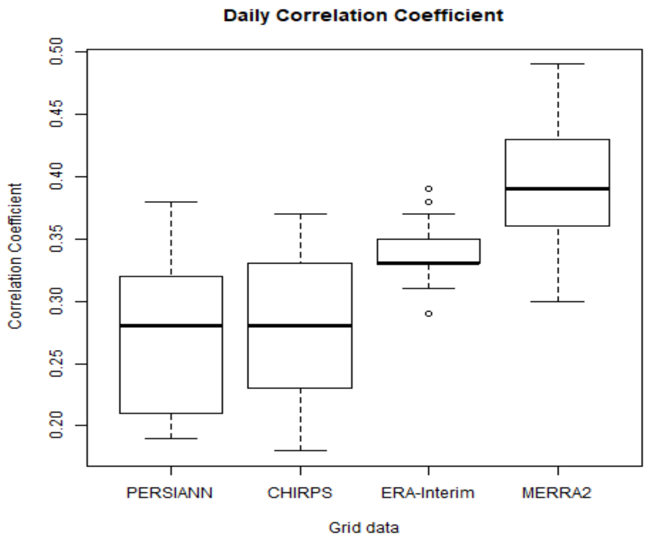
2.4 Future Climate Projection – QC

- ✓ Observation data for period 1987-2016
- ✓ Grid data extraction and comparison / Using R script – R package
- ✓ Quality control
  - Grid data by country
    - CHIRPS: ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/global_daily/netcdf/
    - PERSIANN-CDR: https://www.ncei.noaa.gov/data/precipitation-persiann/access/
    - ERA-Interim: http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/
    - MERRA2: https://disc.gsfc.nasa.gov/datasets?keywords=%22MERRA-2%22&page=1&source=Models%2FAnalyses%20MERRA-2



```
# Remove global environment
rm(list = ls(all = TRUE))

# Load library
library("rGridData")

# Install required packages
Install.Required.Packages()

# Setting working environment
EnvList = Set.Working.Environment (envfile="D:/2018-SDTP/Tools/rGridData.yaml")
# EnvList = Set.Working.Environment (envfile="C:/R_Project/rGridData/rGridData_VNM.yaml")

# Run Extraction code
do.call(Extract.Persiann, EnvList)
do.call(Extract.Chirps, EnvList)
do.call(Extract.EraInterim, EnvList)
do.call(Extract.Merra2, EnvList)

# Run Comparison code
do.call(Comparison.Summary, EnvList)
do.call(Comparison.Summary.Graph, EnvList)
```

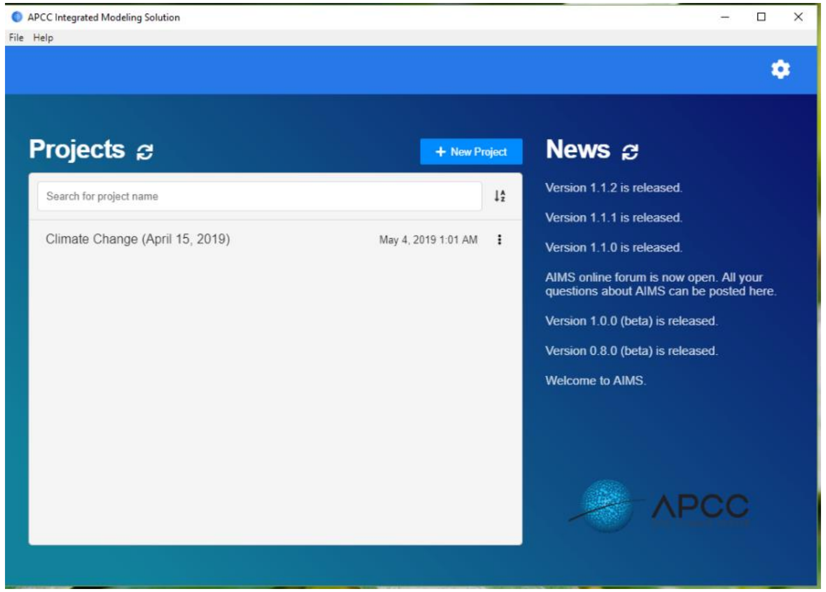
Data type		descriptions				
		Spatial scale	Temporal scale of raw data	variables provided	data period	Update
Satellite	CHIRPS-p25	25 km	daily	prec only	1981~2018	monthly update with 1-month delay
	PERSIANN	25 km	daily	prec only	1983~2017	Annual update
Reanalysis	MERRA2	50 km	hourly	Precipitation, Max./Min. Temperature	1980~2018	monthly update with 1-month delay
	ERA-Interim	75 km	prec: 12-hourly temp: 4-hourly	Precipitation, Max./Min. Temperature	1979~2018	monthly update with 1-month delay



- ✓ After Quality Control(QC), station data is used in AIMS.

2.4 Future Climate Projection – AIMS Module

- AIMS module - free and open source module.
- Available from www.aims.apcc21.org
- R script can be exported and run separately.
- Raw GCM analysis results – 12 best GCMS are used.
- Ensemble Averaging for period S1, S2, S3 – using Matlab and Excel.



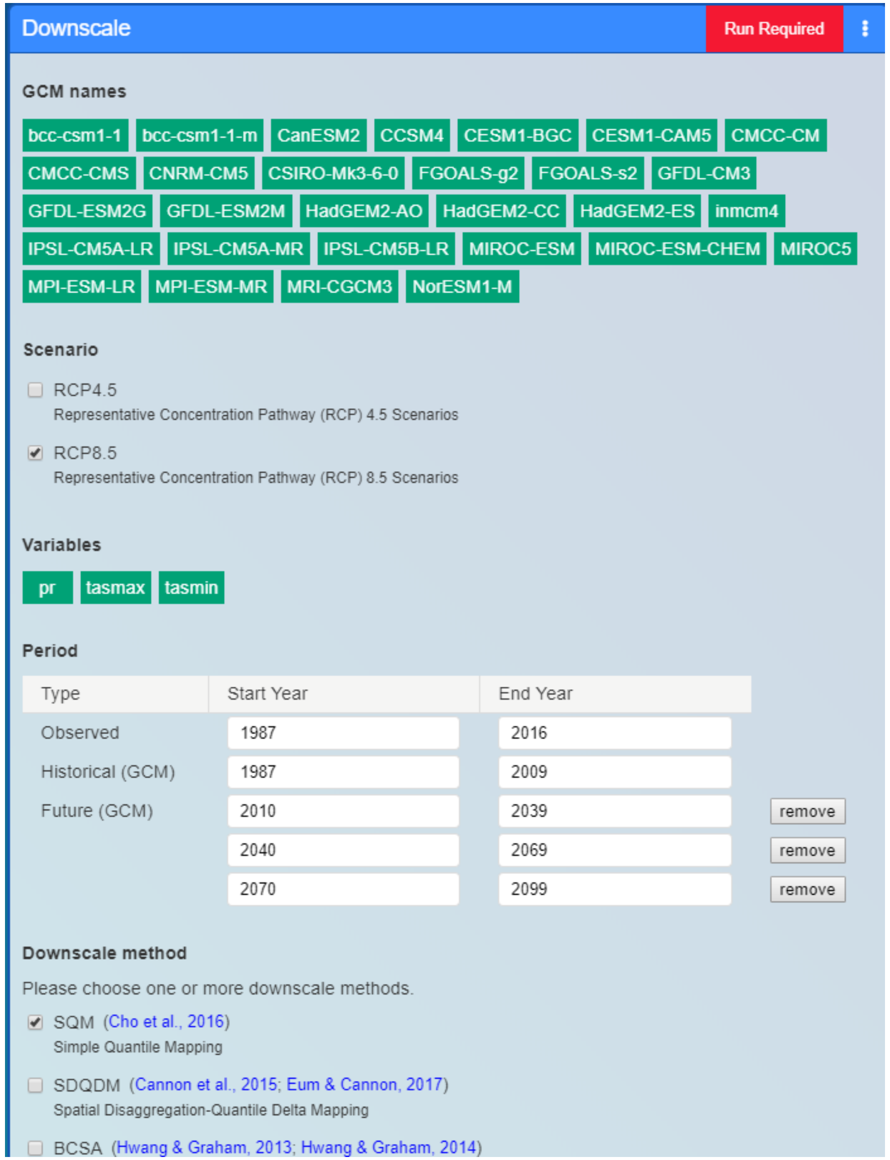
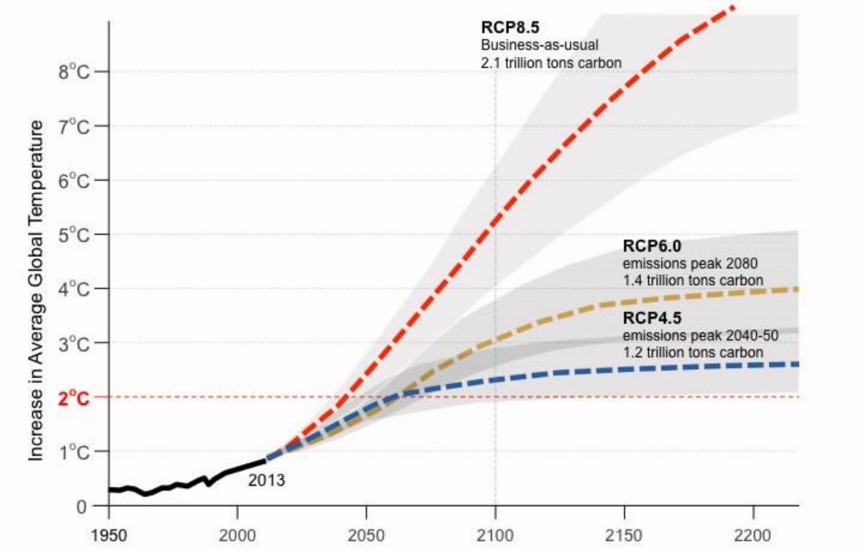


Figure: AIMS User Module

2.4 Future Climate Projection – Rcp Description

- 29 GCMs of CMIP5 downscaled for Nepal
- For RCP scenarios 4.5 and 8.5
- MME of 12 best GCMs are used for the study.
- Three periods : S1 2010-2039, S2 2040-2069, S3 2070-2099

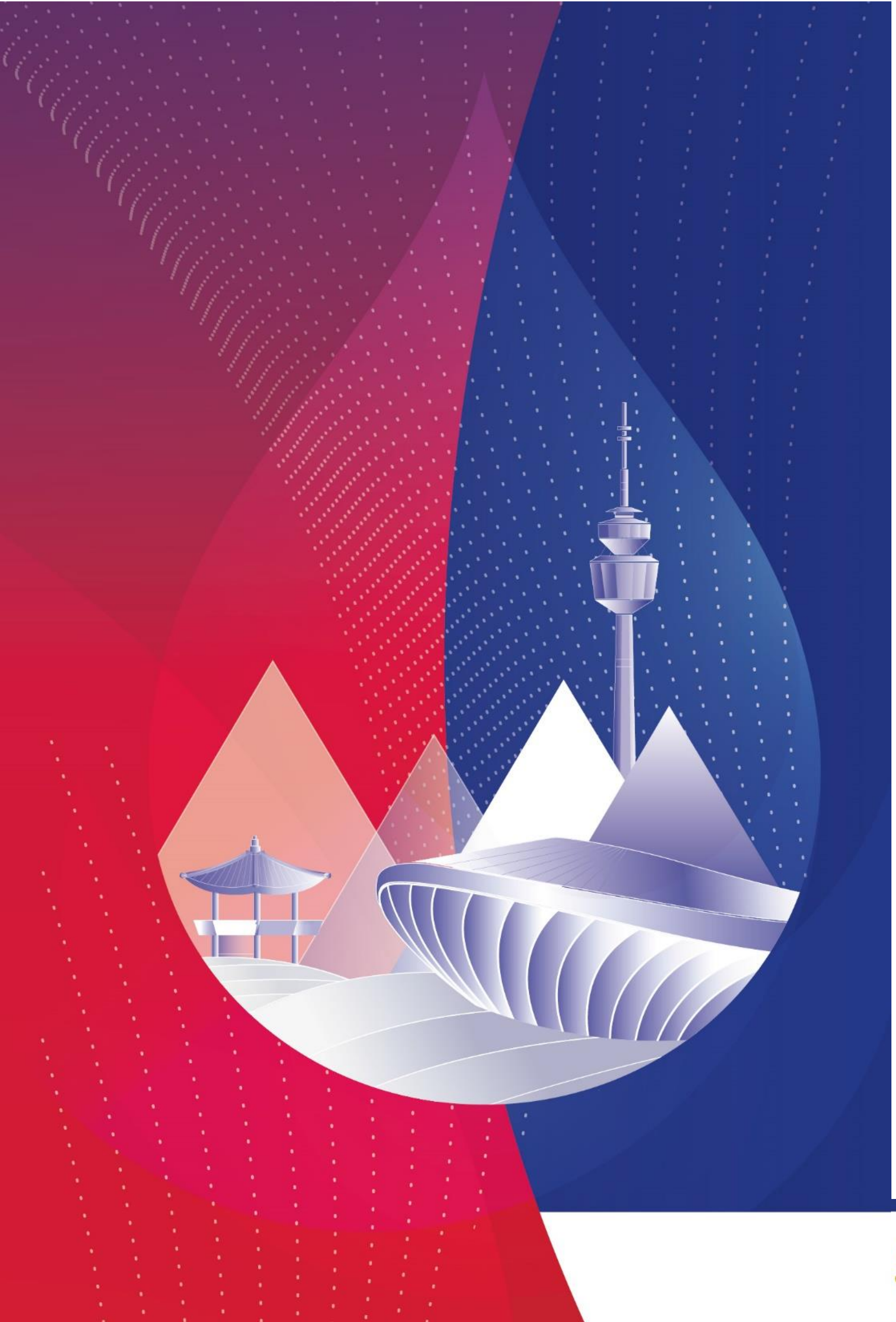


Global temperature projections for various RCP scenarios. Source: IPCC,2013

Rcps'	Description
Rcp 8.5	Rising radiative forcing pathway leading to 8. 5 W/m^2 in 2100
Rcp 6.0	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100
Rcp 4.5	Stabilization without overshoot pathway to 4. 5 W/m^2 at stabilization after 2100
Rcp 2.6	Peak in radiative forcing at ~ 3 W/m^2 before 2 100 and decline.

CMIP Phase 5 Representative Concentration Pathways (RCPs) scenarios (Source: IPCC)

Climate Scenarios	RCP	Period
S1RCP4.5	Rcp4.5	2010-2039
S2RCP4.5	Rcp4.5	2040-2069
S3RCP4.5	Rcp4.5	2070-2099
S1RCP8.5	Rcp8.5	2010-2039
S2RCP8.5	Rcp8.5	2040-2069
S3RCP8.5	Rcp8.5	2070-2099



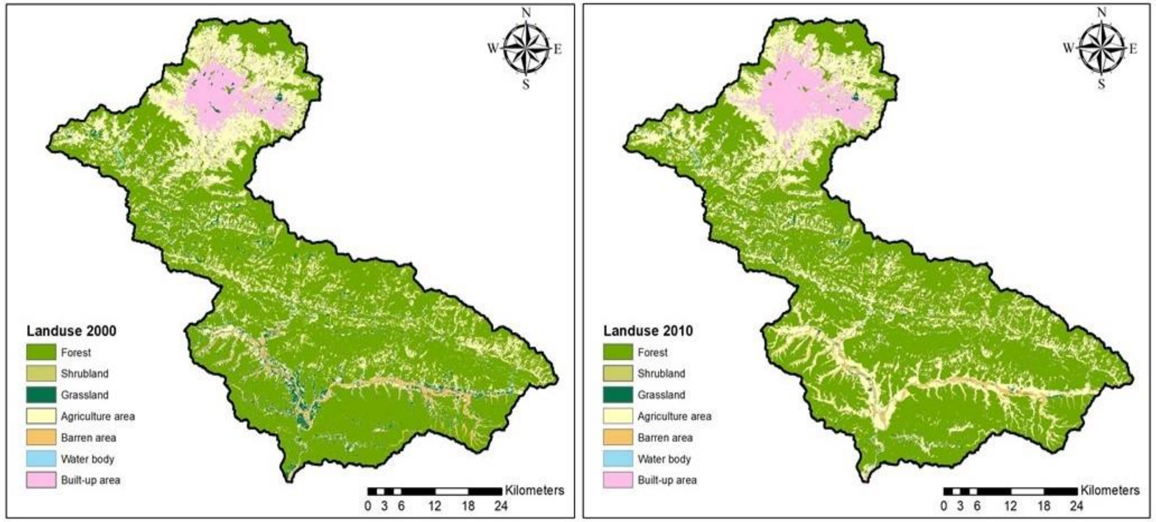
3. Results and Discussion

3.1 Land use and Land Cover Change Assessment

Class	LULC 2000(ha)	LULC 2010(ha)	Change	(%)Change
Forest	181246.64	177803.92	-3442.72	-1.90
Shrubland	2025.96	662.92	-1363.04	-67.28
Grassland	11414.60	5402.48	-6012.12	-52.67
Agriculture	60545.56	69777.56	9232.00	15.25
Barren	7655.64	5003.60	-2652.04	-34.64
Water body	884.20	1034.84	150.64	17.04
Built-up	13124.52	17211.80	4087.28	31.14
Total	276897.12	276897.12	0.00	0.00

LULC change on 2000 and 2010

- Increased population
- Higher demands for food and agriculture
- Urbanization
- Significant change in LULC
- Comparative scenario – high increment on Built-up area and Agriculture and high decrement on Shrubland and Grassland



LULC map 2000 and 2010

3.1 Land use and Land Cover Change Assessment

2010

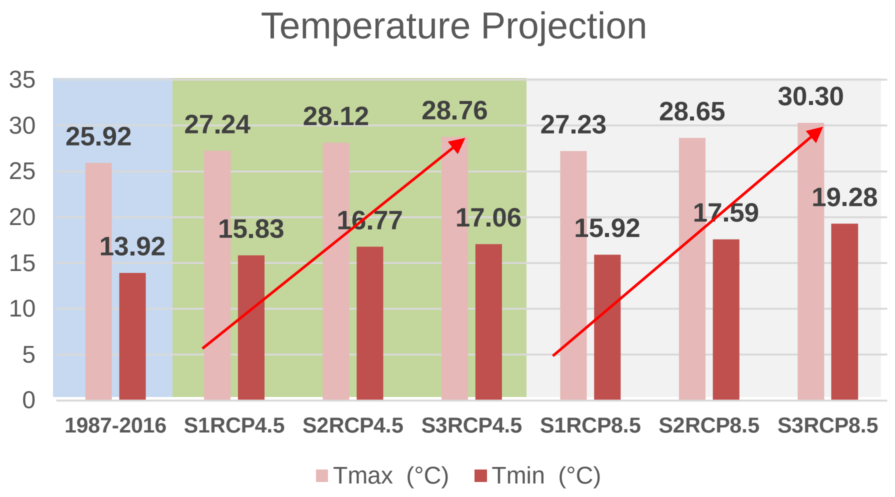
2000

CLASS	Forest	Shrubland	Grassland	Agriculture	Barren	Water body	Built-up	Total
Forest	171000.16	106.48	283.76	9362.92	95.24	89.2	308.88	181246.64
Shrubland	551	473.92	241.2	674.52	42.16	34.56	8.6	2025.96
Grassland	886.04	47.84	1963.28	7555.8	543.72	156.12	261.8	11414.6
Agriculture	5202.24	14.88	2653.44	48755.88	391.12	147.04	3380.96	60545.56
Barren	133	12.08	213.08	3194.24	3737.16	253.04	113.04	7655.64
Water body	31.48	7.72	47.72	234.2	194.2	354.88	14	884.2
Built-up	0	0	0	0	0	0	13124.52	13124.52
								276897.12

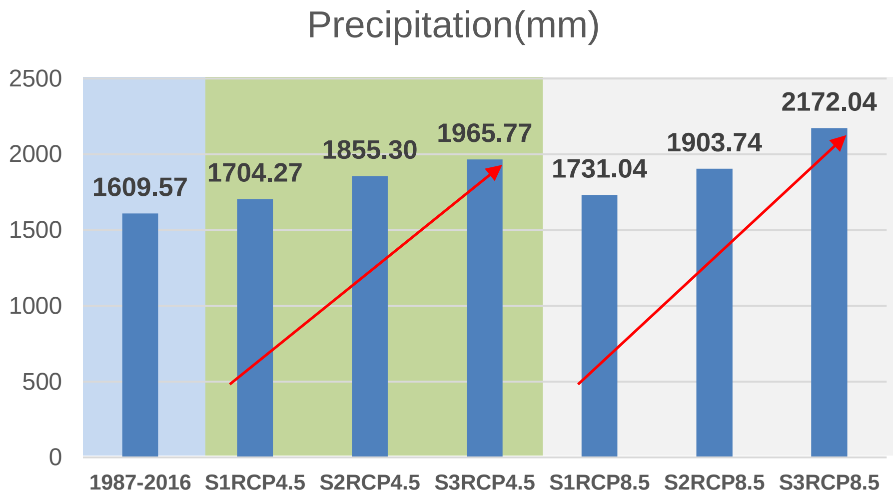
Conversion from one class to another on LULC of 2000 and 2010

- Rate of conversion to agriculture land from other Land use is highest.
- Also conversion to Built up area is significant from other classes.
- Attributable to increased population and urbanization
- Significant fluctuation on Ecosystem service provisions.

3.2 Future climate projection



- Compared to baseline period: 1987-2016
- Average temperature is expected to increase by 1.62°C by the end of 2030, 2.53°C by the end of 2060 and 2.99°C by 2100 under RCP 4.5 scenario.
- Likewise, under RCP 8.5, average temperature is expected to increase by 1.65°C C by the end of 2030 , 3.20°C by the end of 2060 & 4.87°C by 2100



- Under both Rcp scenarios, precipitations is increasing linearly from S1 to S3 periods.
- This increased temperature and precipitation has significant impacts on Ecosystem service provision.

3.3 Water Yield

		2000		2010	
Sub basin	Area	Precip (mm)	WY (m^3/ha)	Precip (mm)	WY (m^3/ha)
1	21393.24	1775.44	11037.84	1672.57	10651.14
2	66396.00	1695.71	10659.63	1671.58	11013.60
3	43520.56	1945.75	12539.44	1850.32	12231.78
4	35195.92	1837.08	11594.40	1758.57	11425.20
5	36103.44	2223.06	15275.12	2045.25	14087.72
6	52777.16	1738.20	10711.38	1612.74	10085.51
7	21510.80	1941.49	12278.39	1755.11	11042.91
		Avg = 1879.5		Avg = 1766.5	

- Case 1: 1996-2005 Precipitation data, 2000 LULC,
- Case 2: 2006-2015 Precipitation data, 2010 LULC
- Sub-basin 5 has highest water yield in both cases.
- With reduction on Average precipitation, Water yield is reduced on case 2.
- Also, as it is function of reference evapotranspiration, with increment on built-up area on sub-basin 2 on 2010, water yield is increased in contrast to overall reduction of WY in basin.

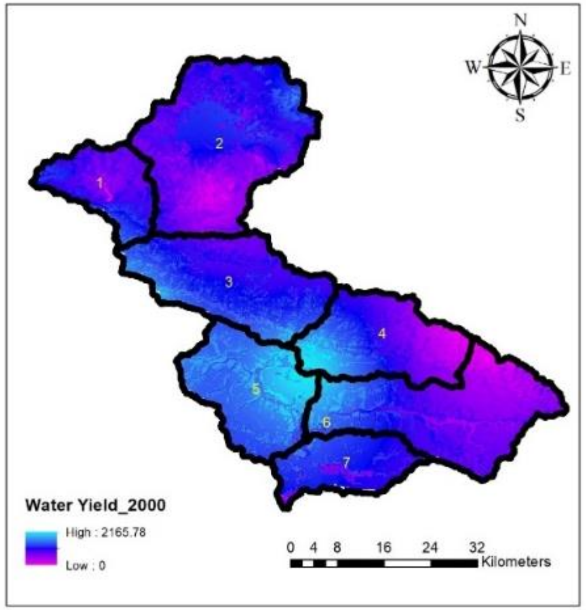


Figure Water yield with LULC 2000

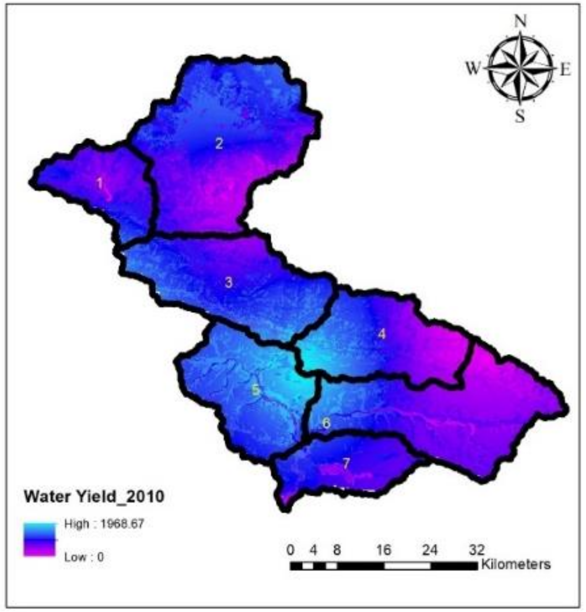


Figure Water yield with LULC 2010

Urban Flooding

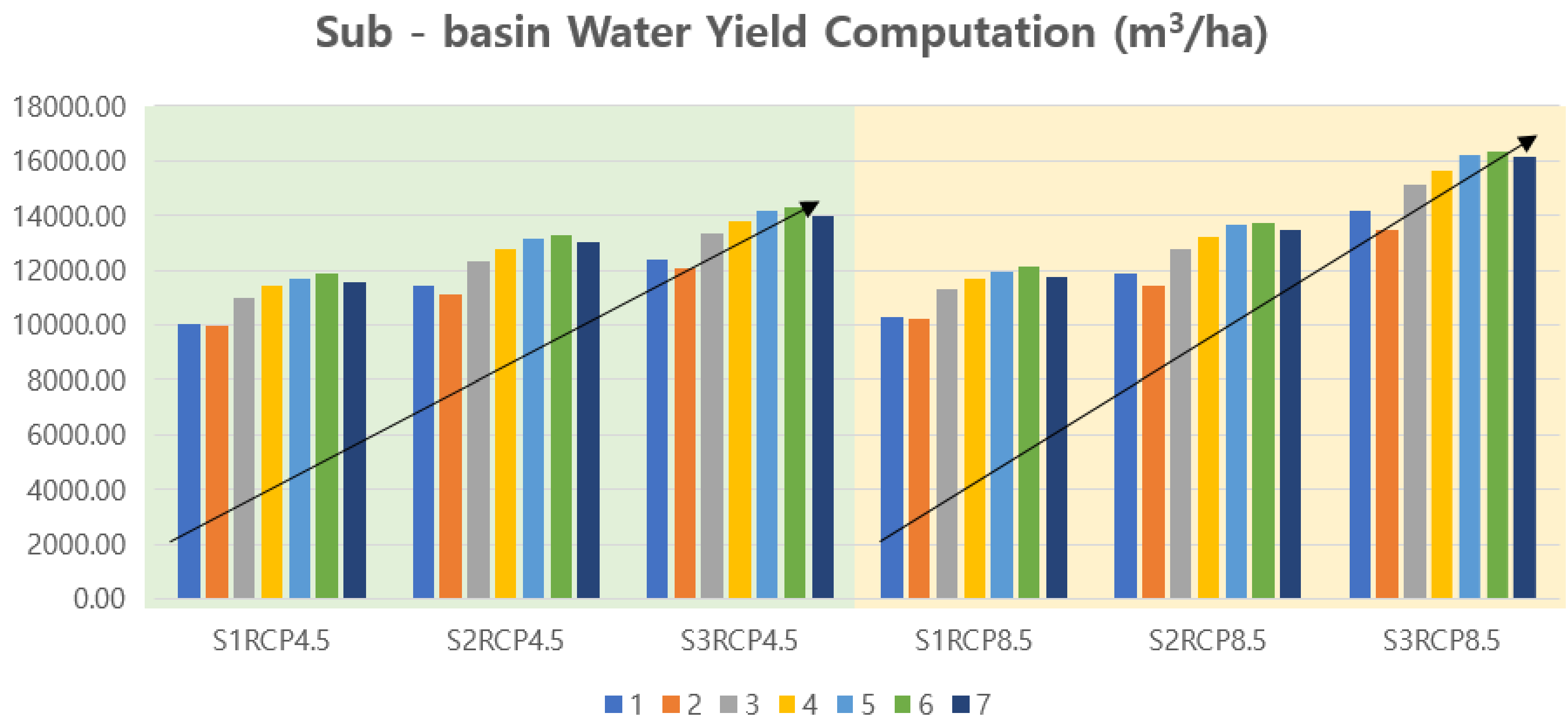
Infrastructural incapability to counteract increased water yield!!

Location: Bhaktapur, Central Nepal

Picture Source: The Himalayan Times daily

Date: Monsoon 2019!!

3.3 Water Yield : Computation for future period



Under both RCP scenarios, WY is projected to increase – Sub basin 6 having highest yield and sub-basin 2 lowest yield.

3.4 Soil loss computation using RUSLE

	2010		2000	
Landuse	Average Rate (t/ha/yr)	Soil Loss (MT/yr)	Average Rate (t/ha/yr)	Soil Loss (MT/yr)
Shrubland	199.93	0.14	110.65	0.23
Water	65.83	0.07	51.36	0.05
Barren	225.62	1.12	121.23	0.92
Grass	108.05	0.59	75.09	0.86
Built	9.98	0.17	9.22	0.12
Forest	35.66	6.30	40.13	7.22
Agriculture	173.58	12.09	198.40	11.99
Total		20.46		21.38

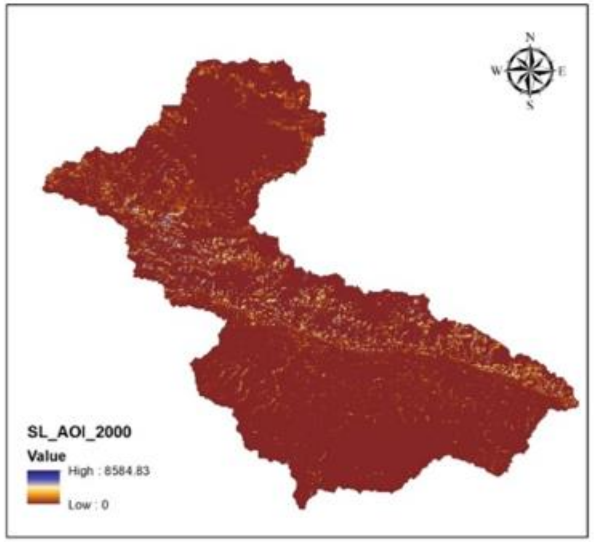


Figure Soil loss computation on 2000 LULC

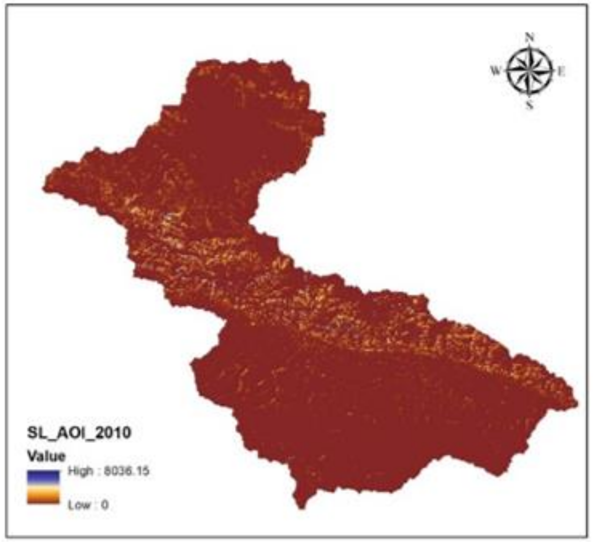
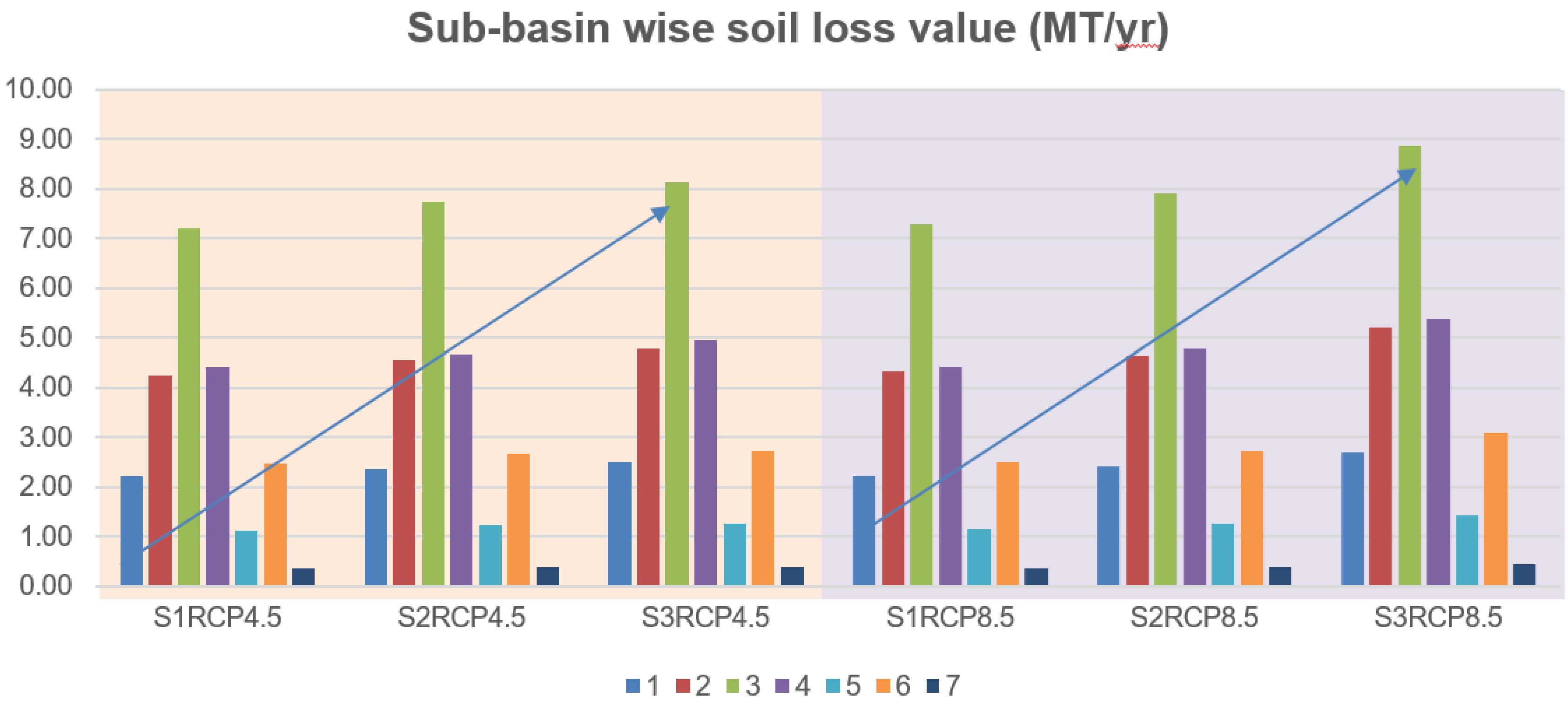


Figure Soil loss computation on 2010 LULC

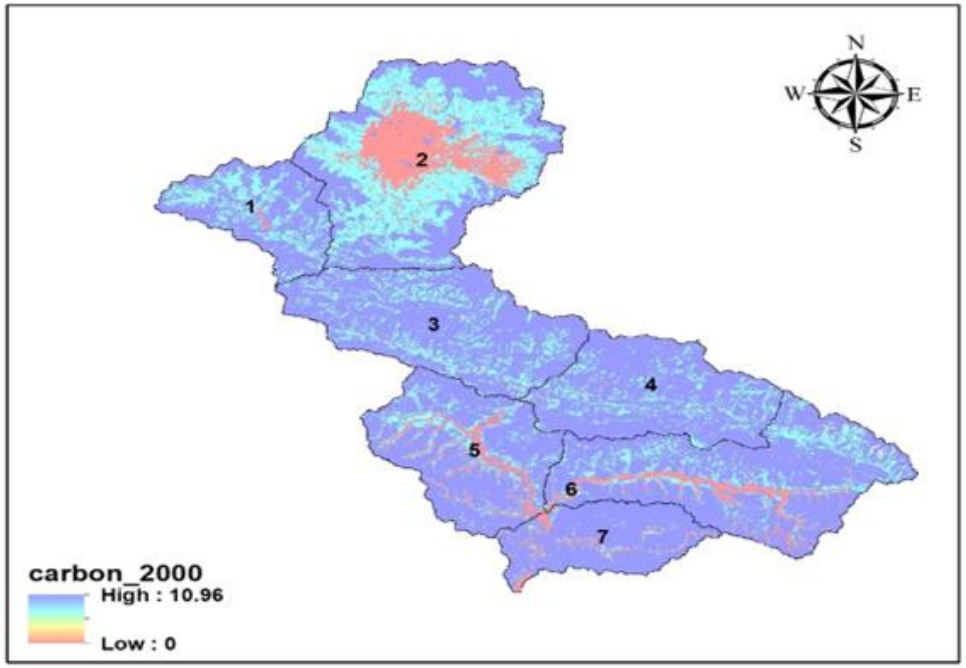
- Soil loss(SL) is also highly affected by rainfall-runoff erosivity, factor of rainfall.
- For 2010 LULC, rate of SL is highest on Agriculture, followed by barren and shrubland.
- For 2000 LULC, rate of SL is highest on barren followed by shrubland and agriculture.
- As the upper part of the basin is highly dominated by agriculture, in both cases, total soil loss is highest from Agriculture area.
- Most sensitive issue with increasing trend.

3.4 Soil loss computation using RUSLE

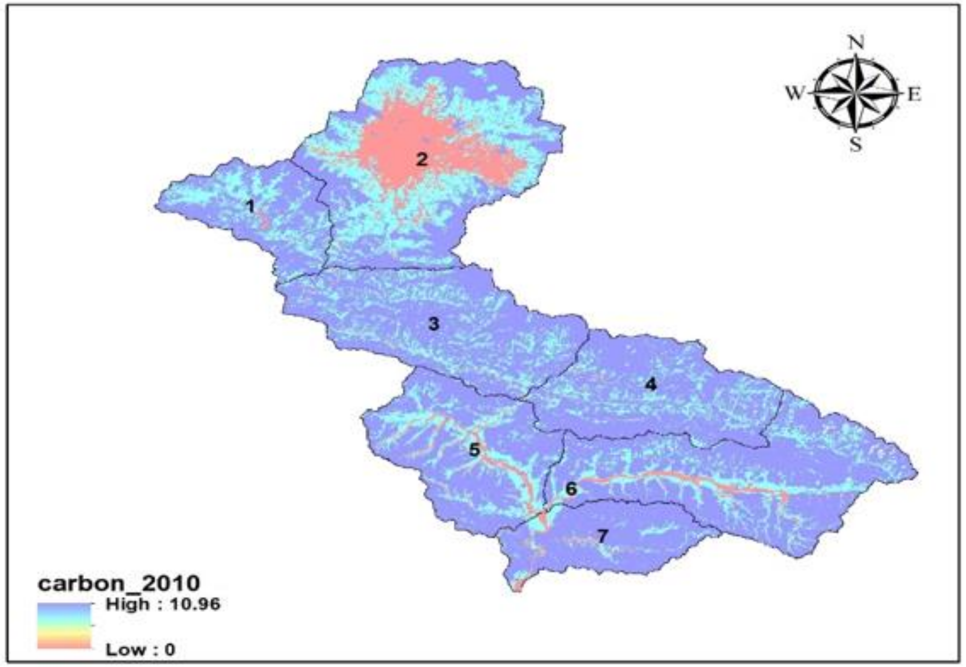


- With increasing precipitation, SL is projected to be linearly increasing from S1 period to S3 period in both scenarios in all basins.
- Soil loss is highest on sub-basin 3 followed by sub-basin 4 and sub-basin 2.
- Baseline 2010 LULC - Lack of proper land use policy and agriculture system further exacerbates the case.

3.5 Carbon Storage mapping



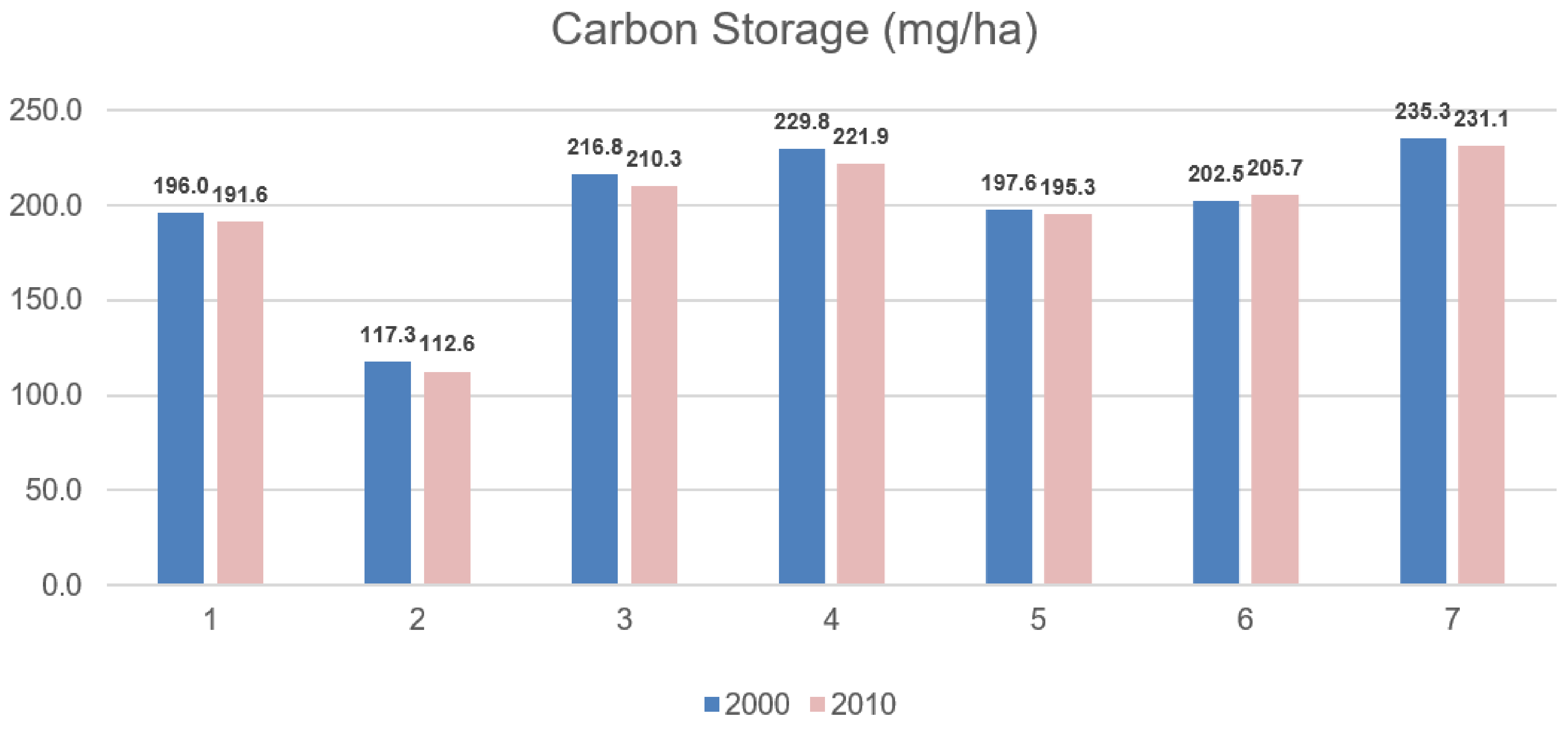
Carbon storage map 2000



Carbon storage map 2010

With significant conversion of Land use and land cover from intact natural system to agriculture and built-up, total carbon storage is reduced by 969923Mg.

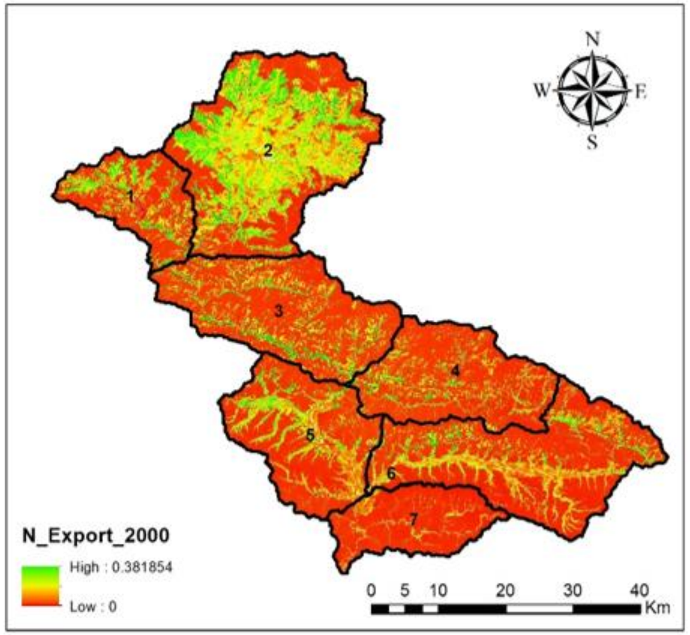
3.5 Carbon Storage mapping



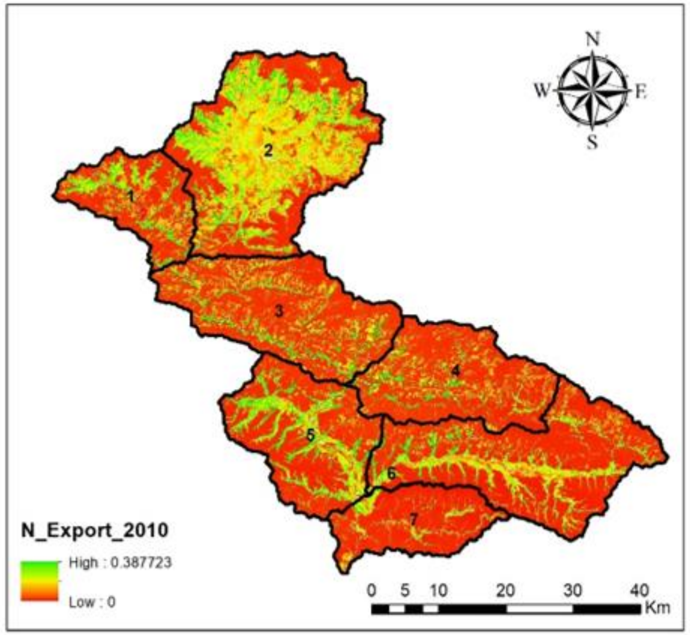
- Sub-basin 2, incorporates major residential and agricultural area – Kathmandu valley and capital city – has lowest carbon storage.
- On comparative study – reduction is highest on sub-basin 4 followed by sub-basin 2.
- Land use policy – incorporation of map of area of highest/lowest carbon storage – reduces risk of loss of carbon sink - promotes sustainable ES provision.

3.5 Nitrogen export mapping

		N_2000		N_2010	
Sub basin	Area	N_exp_tot	kg/ha	N_exp_tot	kg/ha
1	21393.24	17484.005	0.817	19566.571	0.915
2	66396	89765.125	1.352	93065.662	1.402
3	43520.56	29400.787	0.676	32843.554	0.755
4	35195.92	19181.335	0.545	22529.833	0.640
5	36103.44	24561.187	0.680	35622.681	0.987
6	52777.16	30688.987	0.581	37837.433	0.717
7	21510.8	5403.696	0.251	9510.298	0.442
		216485.122		250976.031	



Nitrogen export map 2000

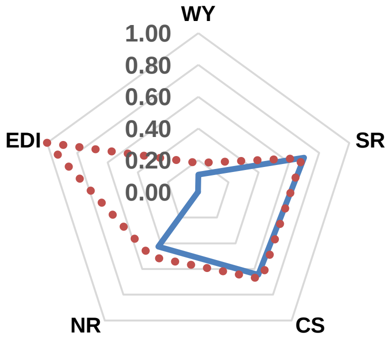


Nitrogen export map 2010

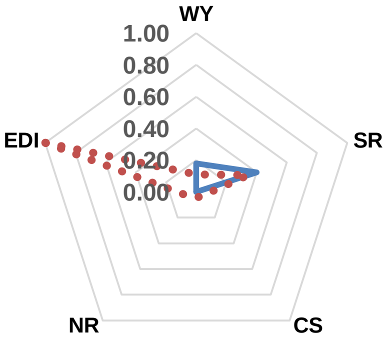
- Nitrogen load are generated from various point and non-point source pollution.
- Highest on Sub-basin 2 in both cases.
- Highly dependent on LULC

3.6 Relative Comparison of ES on sub-basins and periods(2000-2010)

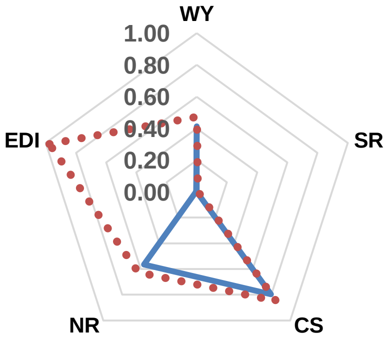
Sub-basin 1



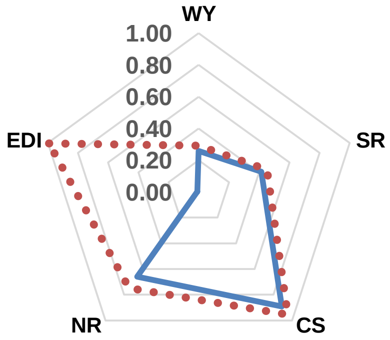
Sub-basin 2

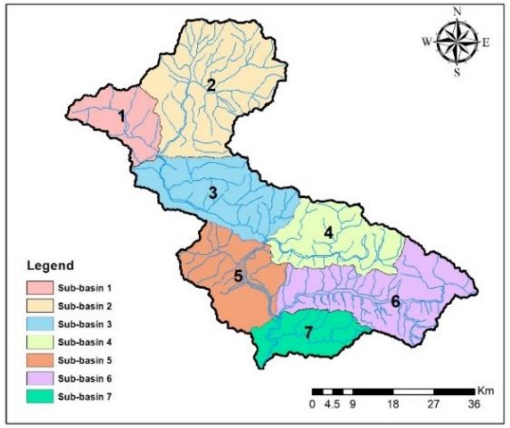


Sub-basin 3

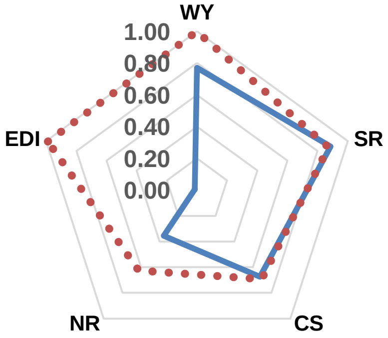


Sub-basin 4

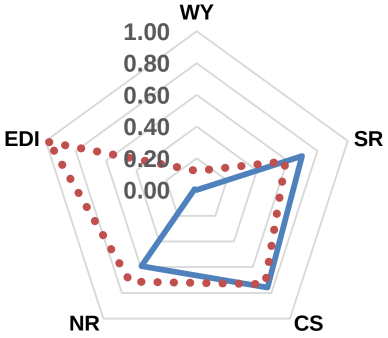




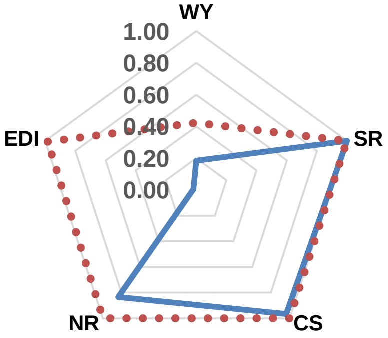
Sub-basin 5



Sub-basin 6



Sub-basin 7



2000 **2010**

WY-Water yield SR-Soil Retention CS-Carbon Storage
NR-Nitrogen Retention EDI-Effective Drought Index

3.7 Discussion

ES are rescaled on a range on 0 to 1, 0 being lowest provision and 1 being highest when compared on all seven watersheds on LULC of 2000 and 2010 and corresponding climate.

The provision of overall ES service is lowest on sub-basin 2 and highest on sub-basin 7 on both time periods.

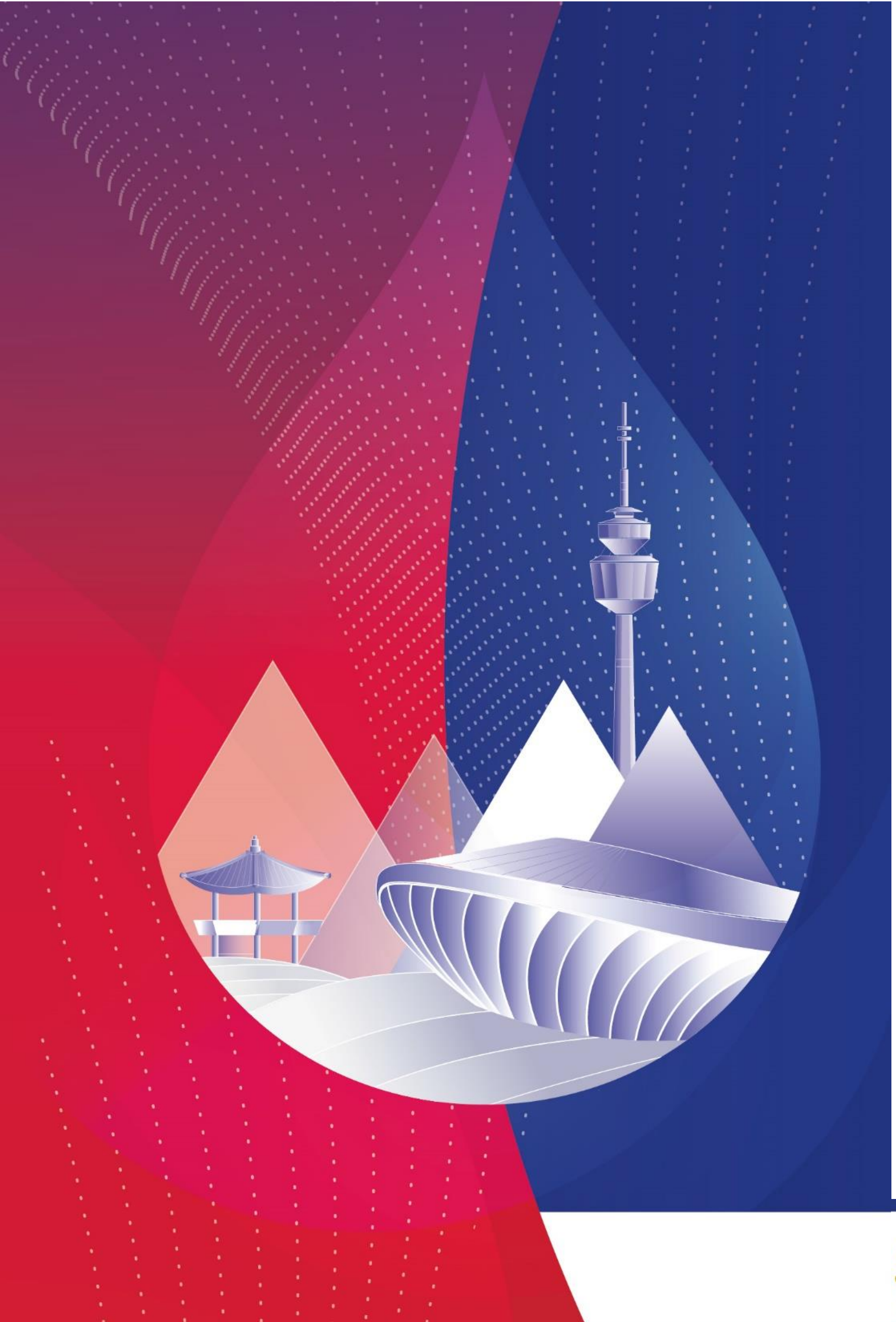
Sub-basin 2 has lowest carbon storage and nitrogen retention – attributable to major residential and agricultural area.

Sub-basin 7 has highest Soil retention, nitrogen retention and carbon storage – attributable to intact / undisturbed nature.

Sub-basin 3 has lowest soil retention and Sub-basin 6 has lowest water yield.

Sub-basin 2 demands urgent measures for preservation as ES are on constant decrease.

Ranking of services can be made based on priorities of inhabitants of sub-basin.



4. CONCLUSION

4.Conclusion

1. Ecosystems provide a range of services, many of which are of fundamental importance to human well being for health, livelihoods, and survival.

2. Conversion of land use from one class to another significantly alters ES.

3. The projection of climate change has indicated the acceleration on the water cycle at a global scale, resulting in more frequent climate events which will impact provision of ecosystem services.

4. Proper plans and mitigation measures are necessary to combat the impacts of climate change.

5. Cost of preservation of ES can be valued as avoided treatment cost or improved quality.

6. ES maps of – where they originate- their storage - their export – on a sub-basin scale – on present and future climatic conditions - helps land use decisions and policy making for sustainable designs and systems.

Any comments and suggestions are highly appreciated!! ☺

Thank you for your attention.

For further queries:

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