IMPACT OF PROJECTED CLIMATE CHANGE ON SEDIMENT YIELD IN THE CHALIYAR RIVER BASIN

ANSA THASNEEM S, SANTOSH G THAMPI & CHITHRA. N. R.

NIT Calicut, Kozhikode, Kerala, India

e-mail: ansathsnm@gmail.com,santosh@nitc.ac.in, chithranr@nitc.ac.in

INTRODUCTION

- Scientific sources have predicted global warming and climate change due to increase in greenhouse gas concentrations in the atmosphere
- The Intergovernmental Panel on Climate Change (IPCC) forecasts a rise of 0.3 to 1.7 °C for the lowest and 2.6 to 4.8 °C for the highest emission scenarios during the 21st centaury
- This can cause variation in the timing, intensity and frequency of precipitation events

Contd….

- Variation in rainfall, vegetation cover, geological processes and runoff from the watershed can affect sediment erosion and sediment delivery at the catchment outlet
- Changes in water and sediment discharges in rivers would affect morphodynamics, as well as the performance of existing hydraulic structures such as reservoirs, weirs/ barrages, water supply intakes and other flood controlling structures
- Natural habitats, riverine ecosystems are also likely to be affected due to variation in discharge and sediment load

Objectives

- To estimate the sediment yield from a watershed in the present scenario
- To estimate the sediment yield in future considering climate change
- To suggest management practices based on the results

Study Area

- **Chaliyar river basin, Kerala, India**
  - Chaliyar - the fourth longest river (169km) in Kerala, India
  - Area of the river basin in Kerala is 2530km^2
  - It is bounded by latitudes 11° 06’07”N and 11°33’35”N and longitudes 75°48’45”E and 76°33’00”
- **Physiography**
- Highland (600-2600m), midland(300-600m), low land (300-10m) and coastal plains(10m above MSL)

Contd…….

- **Climate**
- Southwest monsoon (June–August) contributes about 60%, northeast monsoon (September–November) about 25% and pre-monsoon about 15% (April–May) of the total annual precipitation
- December–March is the dry period
- Average annual precipitation in the basin - 3012mm
- The maximum and minimum temperatures - 34◦C and 24◦C respectively.
- The annual average relative humidity ranges from 60% to 90% in summer and 65% to 85% during winter

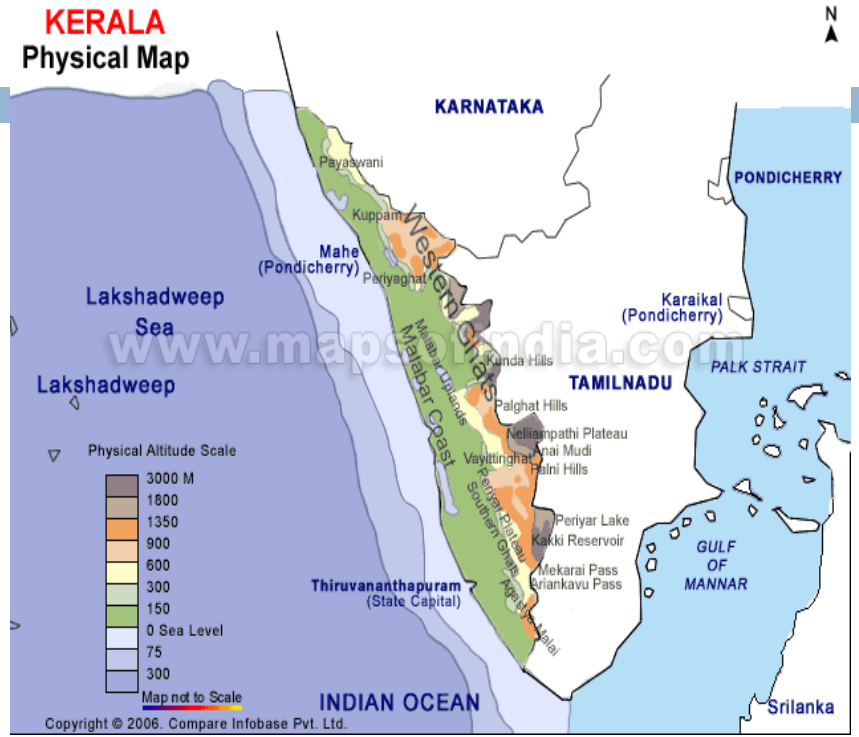


Fig 1: Physical map of Kerala

Fig 2: River map of Kerala

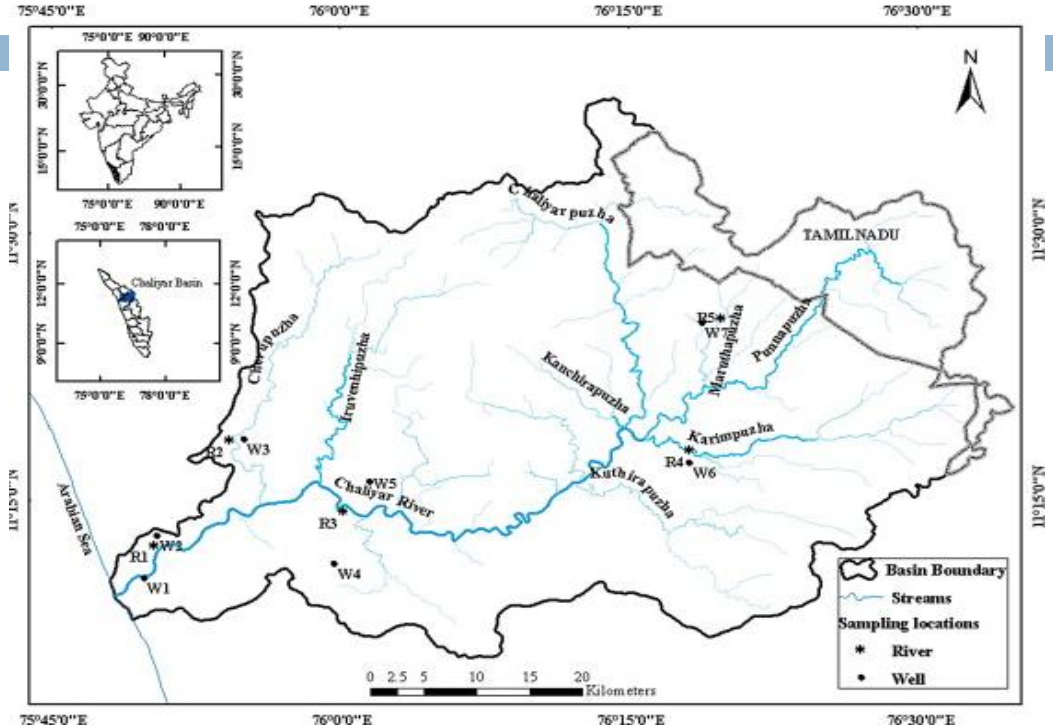


Fig 3: Map of Chaliyar river basin

Methodology

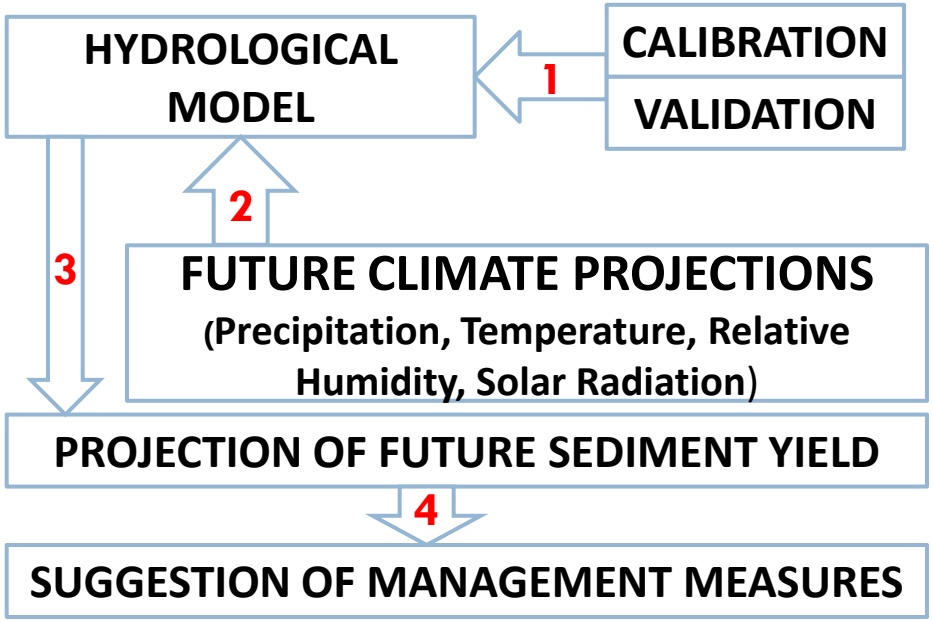


Fig 4: Overall methodology adopted in the study

Hydrological model SWAT

- For modeling purposes, a watershed is partitioned into a number of sub basins
- Input information for each subbasin is grouped into categories such as climate, hydrologic response units, groundwater and the main channel or reach draining the subbasin
- Simulation of hydrology of a watershed is done in two steps
- The land phase of the hydrologic cycle
- The water or routing phase of the hydrologic cycle

Governing equation

Water Balance Equation

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{sweep} - Q_{gw})i \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

SW_t is the final soil water content,
SW_0 is the initial soil water content on day i (mm),
R_{day} is the amount of precipitation on day in mm,
Q_{surf} is the amount of surface runoff on day i in mm,
E_a is the amount of evapotranspiration on day i in mm,
w_{sweep} is the amount of water entering the vadose zone from the soil profile on day i in mm,
Q_{gw} is the amount of return flow on day i in mm

Estimation of run off

- Estimation of runoff is by SCS curve number (CN) method

$$Q = \frac{(R-0.2S)^2}{R+0.2S} \text{.....(2)}$$

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \text{.....(3)}$$

Q=Daily surface runoff (mm)

R=Daily rainfall (mm)

S=Retention parameter

CN= Curve number ranging from $0 \le CN \le 100$

Estimation of sediment yield

- The Modified Universal Soil Loss Equation (MUSLE) estimates the erosion produced by both rainfall and surface runoff flow for each single rain storm

$$Q_{SED} = (11.8 \times Q_{run} \times q_{peak} \times area_{hru})^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CRFG \ldots (4)$$

Q_{SED} is the yields of sediment in a considered interval (day) (tons),
Q_{run} is the volume of surface runoff per unit area (mm/ha),
q_{peak} is the peak runoff rate (m^3/s),

Contd…..

- $area_{hru}$ is the hydrologic response unit area (ha),
- K_{USLE} is the soil erodibility factor of the USLE,
- C_{USLE} is the cover management factor of USLE,
- P_{USLE} is the transport particle factor of USLE,
- LS_{USLE} is the slope length factor of USLE and
- CRFG is the factor of coarse fragment

Input Data and Source

Table 1: SWAT input data and source

Data Type	Source	Scale	Data description/ properties
Topography	Survey of India	1:50000	Elevation, spot height, drainage, boundary
Landuse	Kerala State Landuse Board	1:50000	Land-use classification such as croplands, forests and pastures
Soil	Kerala State Landuse Board	1:250000	Soil classification and physical properties

Input Data and Source

Weather	Meteorological observatory of the CWRDM at Kottamparamba	Daily precipitation, Maximum and minimum temperature (1982-2007)
Streamflow and sediment	Gauging station of the CWC at Kuniyil	Daily discharge , sediment concentration (1982-2007),
Future climate data	CORDEX IITM	Dynamically downscaled data for RCP4.5 and RCP8.5 from REMO 2009 (MPI) (MPI Regional model 2009).Driving GCM MPI-ESM-LR

ARCSWAT Processing

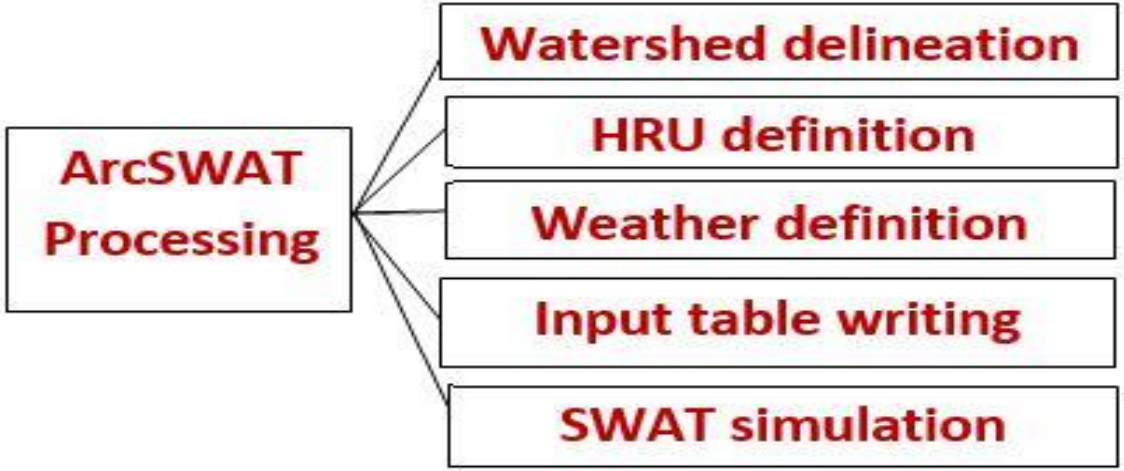
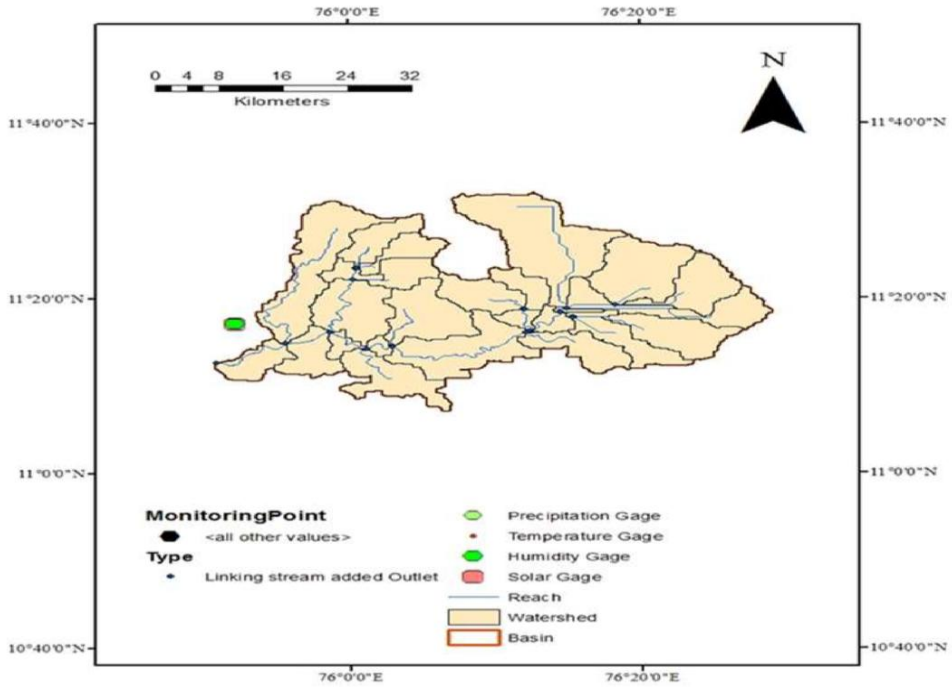


Figure 5: Steps for ArcSWAT Processing

Delineated watershed



- Total area is again divided into 28 sub basins

Fig 6 : Delineated watershed with subbasins

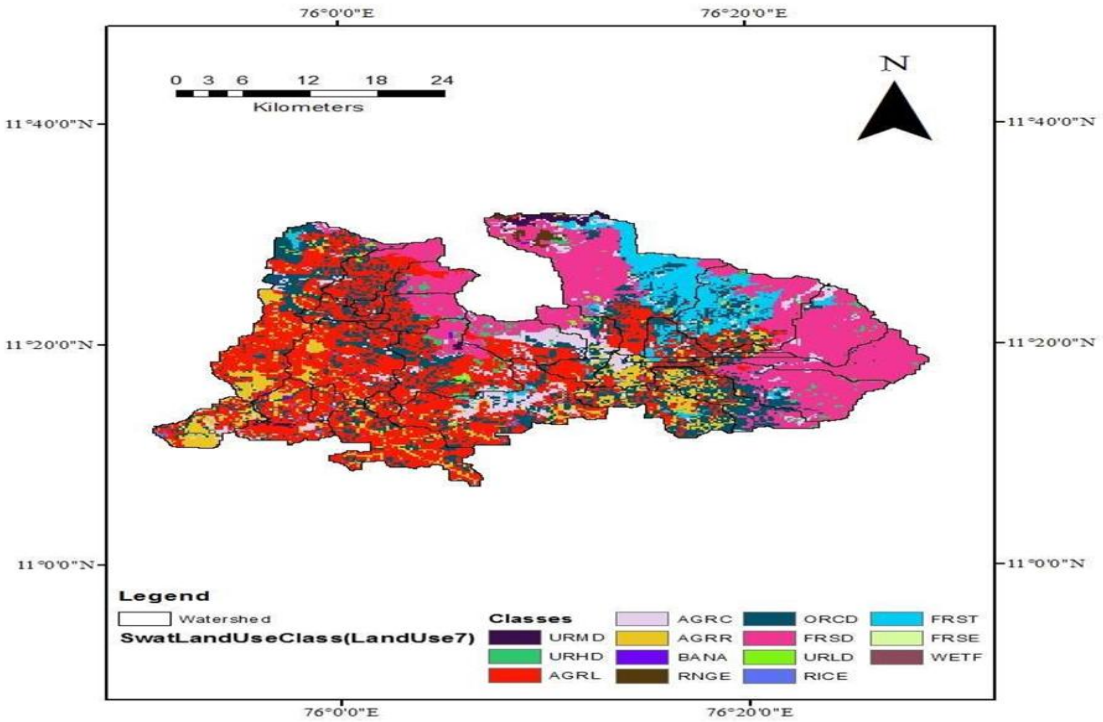


Fig 7: Landuse reclassification of the Chaliyar river basin from SWAT

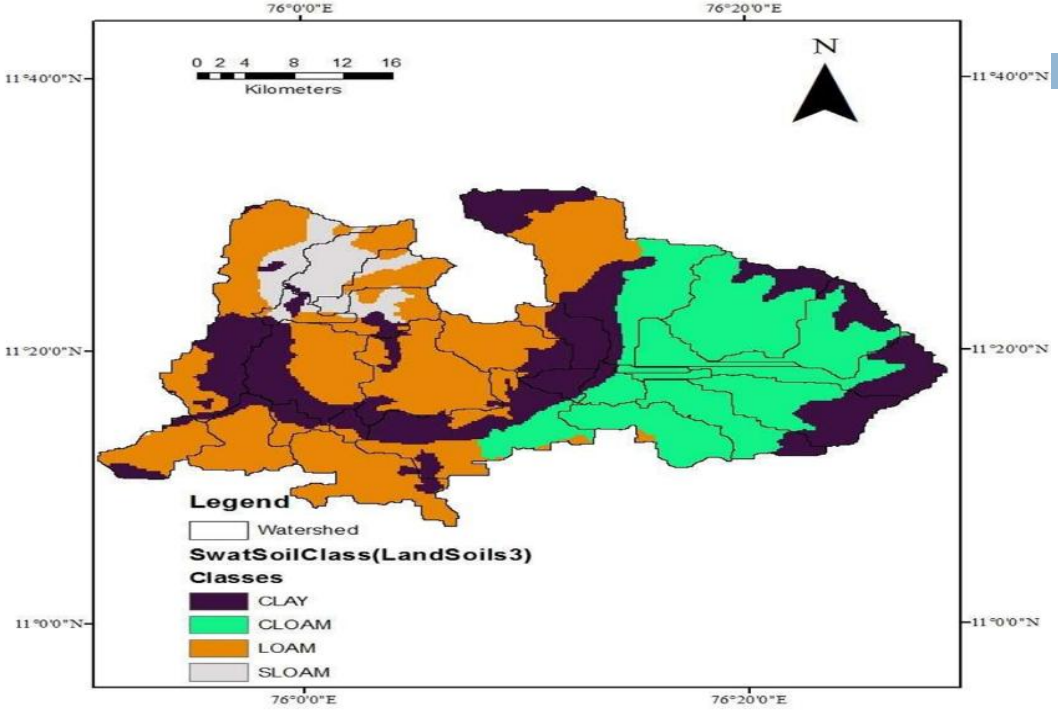


Fig 8: Soil reclassification of the Chaliyar river basin from SWAT

Calibration

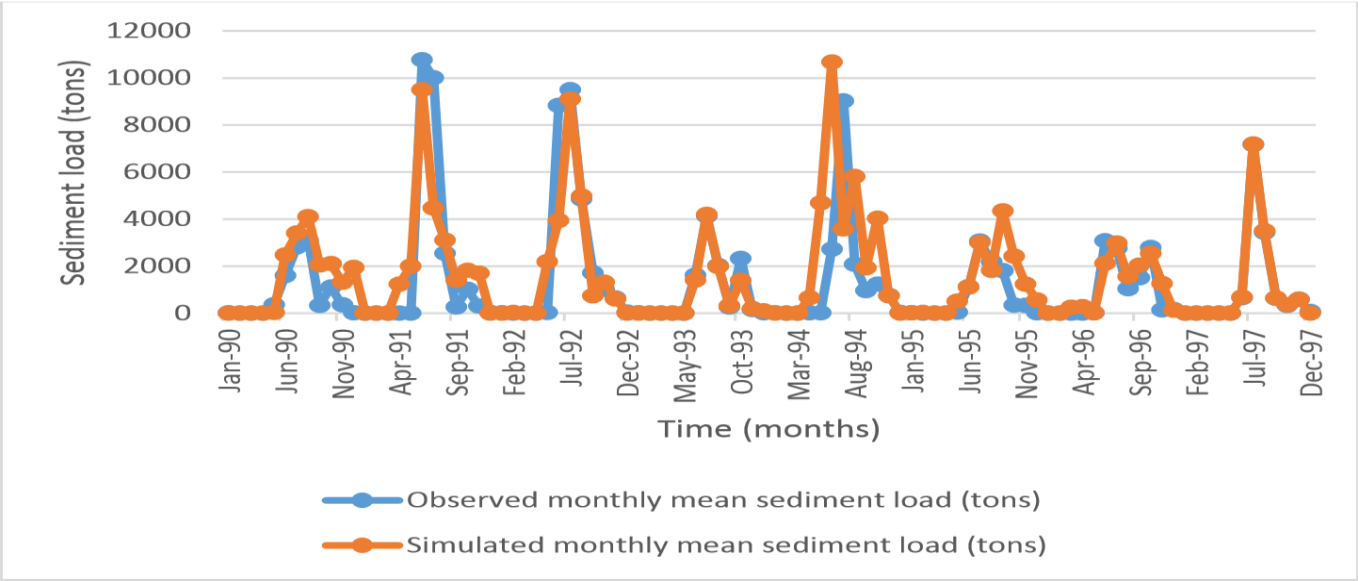
- Sediment data for 8 years from 1990-1997 was used for calibrating the model
- Done using SWAT CUP
- Sufi2 (Sequential Uncertainty Fitting version 2) algorithm is selected for calibration
- It accounts for uncertainties in driving variables (e.g. rainfall), conceptual model, parameters and measured data

Contd…

Table 2: Parameters used for calibration

Parameter	Description	Fitted Value
V__SPCON.bsn	Linear re-entrainment parameter for channel sediment routing	0.00035
V__SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment routing	0.35
V__USLE_C.crop.dat	USLE land cover factor	0.1
V__USLE_P.mgt	USLE equation support practice	0.15
V__CH_COV2.rte	Channel cover factor	0.25
V__CH_COV1.rte	Channel erodibility factor	0.25
V__SLSUBBSN.hru	Average slope length	50
R__ALPHA_BF.gw	Baseflow alpha factor	0.5
V__CH_N2.rte	Manning's n-value for main channel	0.20
R__SOL_AWC.sol	Available water capacity (mm mm−1 soil)	0.25
V__ESCO.bsn	Soil evaporation compensation factor	0.5
V__CN2.mgt	Curve number	84

(Contd…)

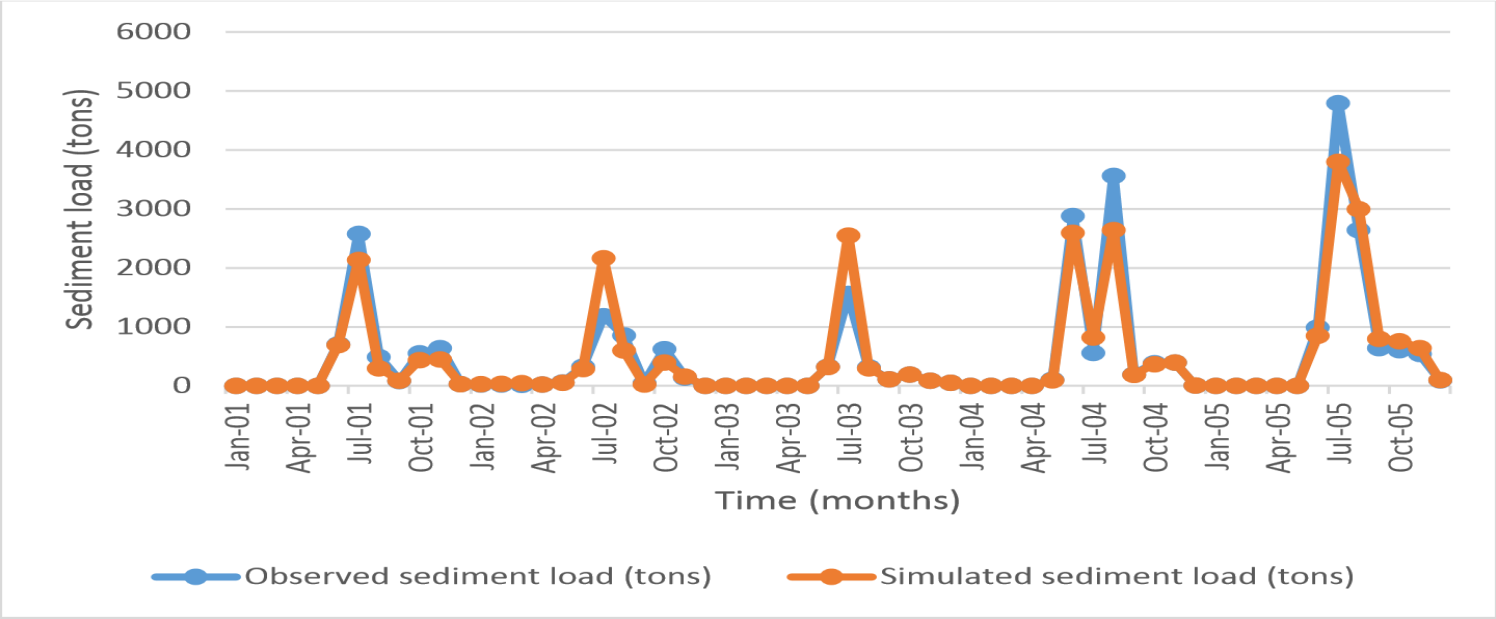


$R^2 = 0.68$

$NSE = 0.64$

Fig. 9: Comparison of observed vs. predicted sediment yield for the calibration period

Validation



$R^2 = 0.70$

$NSE = 0.67$

Fig. 10: Comparison of observed vs. predicted sediment yield for the validation period

Climate Model and Bias Correction

RCM - REMO2009

- Resolution $0.5^0 \times 0.5^0$
- Driving GCM - MPI-ESM-LR
- RCPs considered - RCP8.5 and RCP4.5

Bias correction

- Needed due to systematic (i.e., biases) and random model errors

Delta change method is used in this study

- Uses observations as a basis to produces future time series with dynamics similar to current conditions

Contd…..

- Multiplicative correction is applied for precipitation,relative humidity, (eqns. 5 and 6)
- Additive correction is applied for temperature (eqns. 7 and 8)

$$P^*_{cont}(d) = P_{obs}(d) \qquad \text{……..(5)}$$

$$P^*_{scen}(d) = P_{obs}(d) \times \frac{\mu_m(P_{scen}(d))}{\mu_m(P_{cont}(d))} \qquad \text{……..(6)}$$

$$T^*_{cont}(d) = T_{obs}(d) \qquad \text{……..(7)}$$

$$T^*_{scen}(d) = T_{obs}(d) + \mu_m(T_{scen}(d) - T_{cont}(d)) \qquad \text{……..(8)}$$

Contd…….

where

- μ_m is the mean within the monthly interval
- $P^*_{cont}(d)$ is the final bias corrected precipitation in the control period (RCM simulated),
- $P_{obs}(d)$ is the observed daily precipitation,
- P_{scen}(d) is the daily precipitation while considering the scenario period of the climate model,
- $P^*_{scen}(d)$ is the final bias corrected daily precipitation during the scenario period,
- $T_{cont}{}^*(d)$ is the final bias corrected temperature,
- T_{obs}(d) is the observed daily temperature,
- $T_{scen}(d)$ is the daily temperature while considering the scenario period of the climate model,
- $T^*_{scen}(d)$ is the final bias corrected daily temperature during the scenario period

Projection of future sediment yield

- Sediment yield can change as a result of changes that happen to climatic variables such as precipitation, temperature, relative humidity and solar radiation
- Mean monthly variation of each variable during 2050-2060 under RCP 4.5 and RCP8.5 with respect to the baseline period (1987-2007) is analysed
- Using the bias corrected variables for 2050-2060, sediment yield is projected

Contd .....

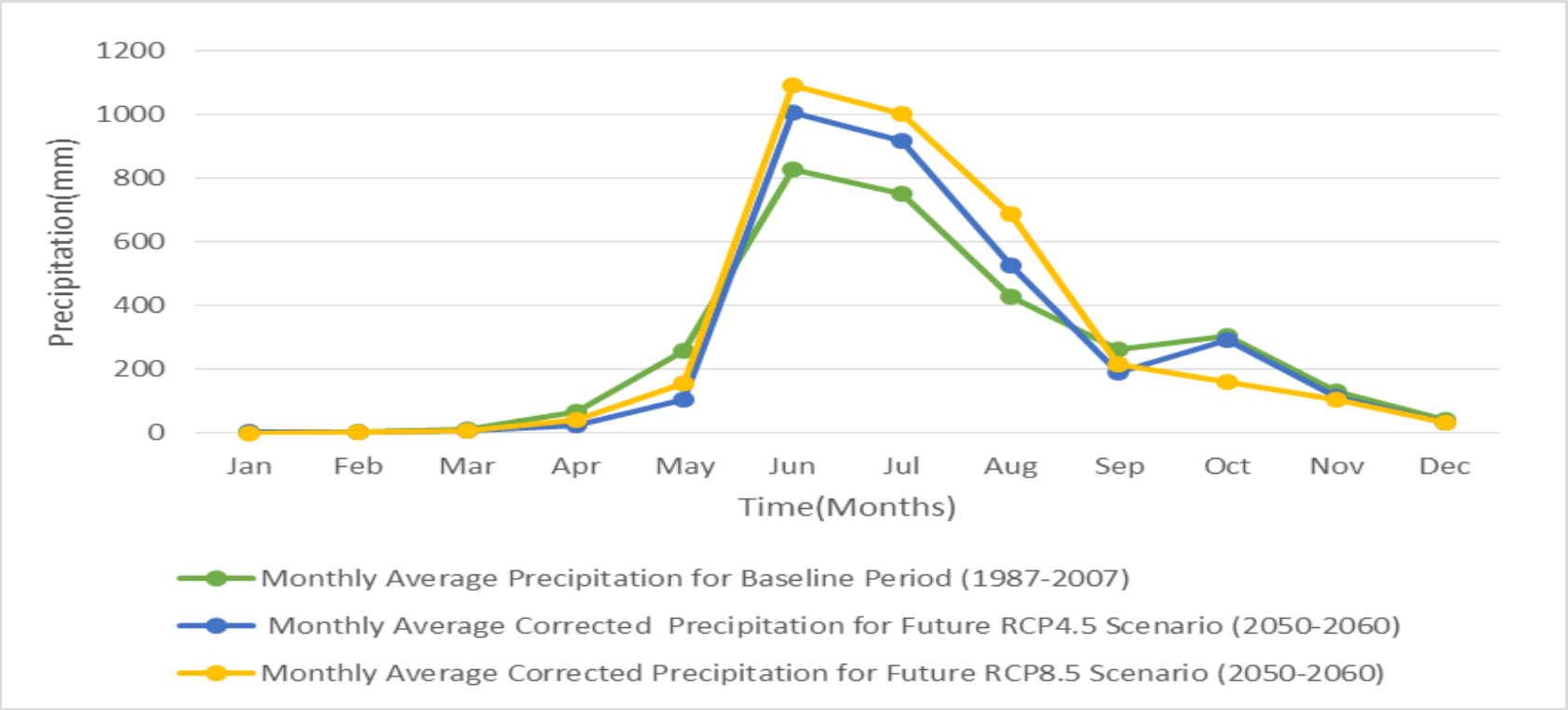


Fig. 11: Plot of monthly average precipitation for the baseline period and under the RCP scenarios

Contd …..

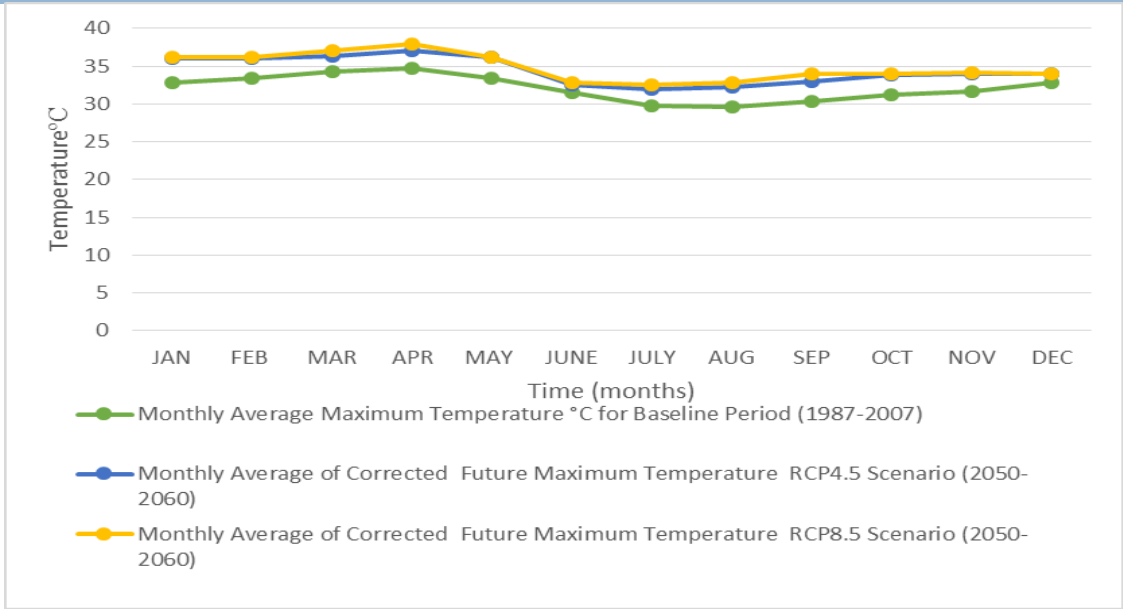


Fig. 12. Plot of monthly average maximum temperature for the baseline period and under the RCP scenarios

Contd …..

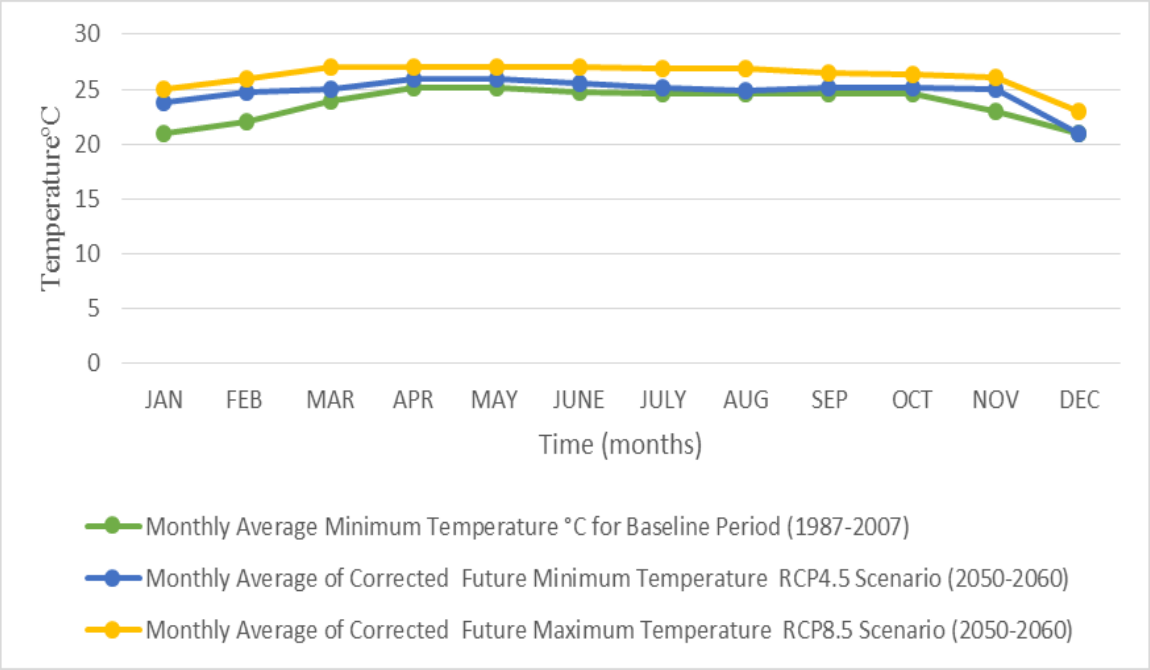


Fig. 13 : Plot of monthly average minimum temperature for the baseline period and under the RCP scenarios

Contd …..

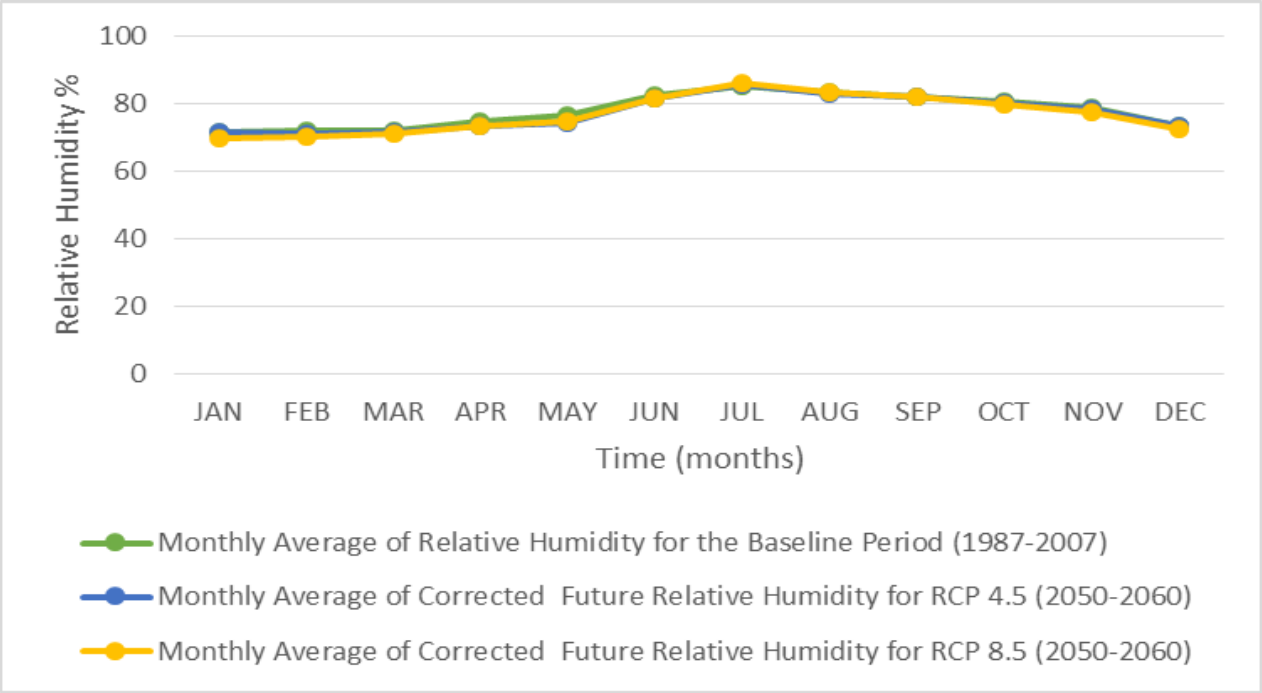


Fig. 14: Plot of monthly average of relative humidity for the baseline period and under the RCP scenarios

Contd …..

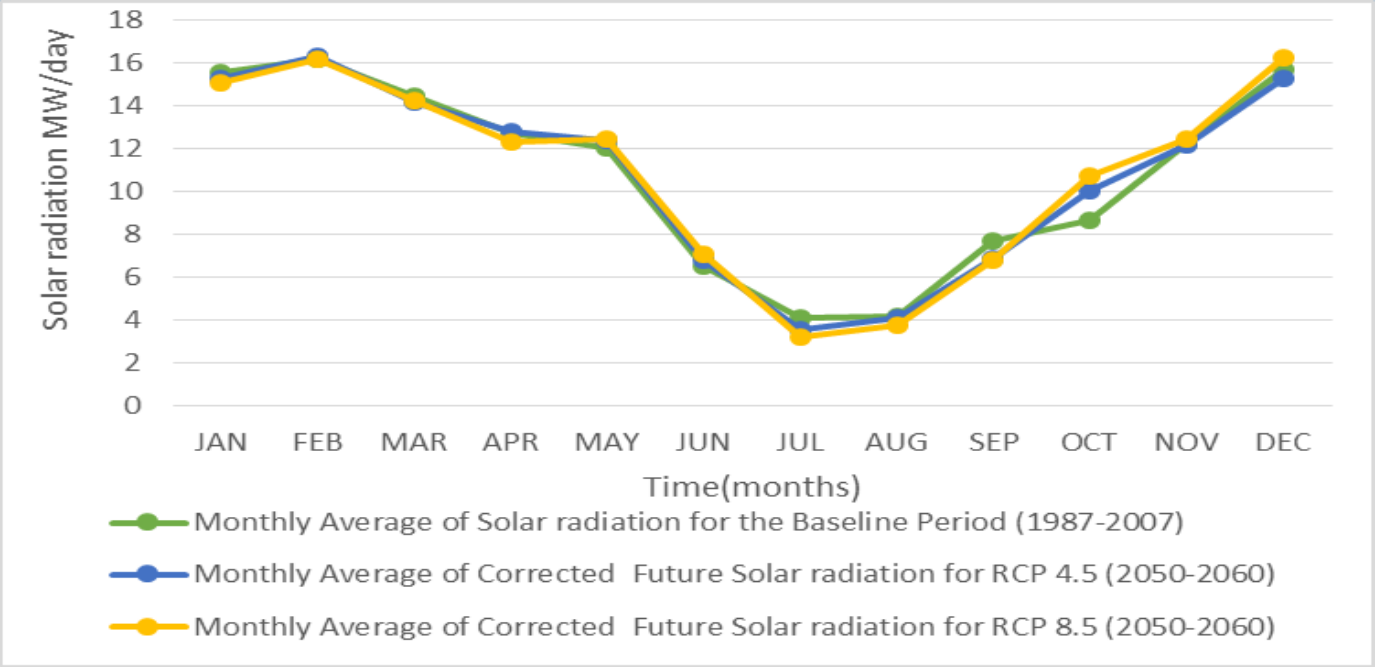


Fig. 15: Plot of monthly average of solar radiation for baseline period and under the RCP scenarios

Contd …..

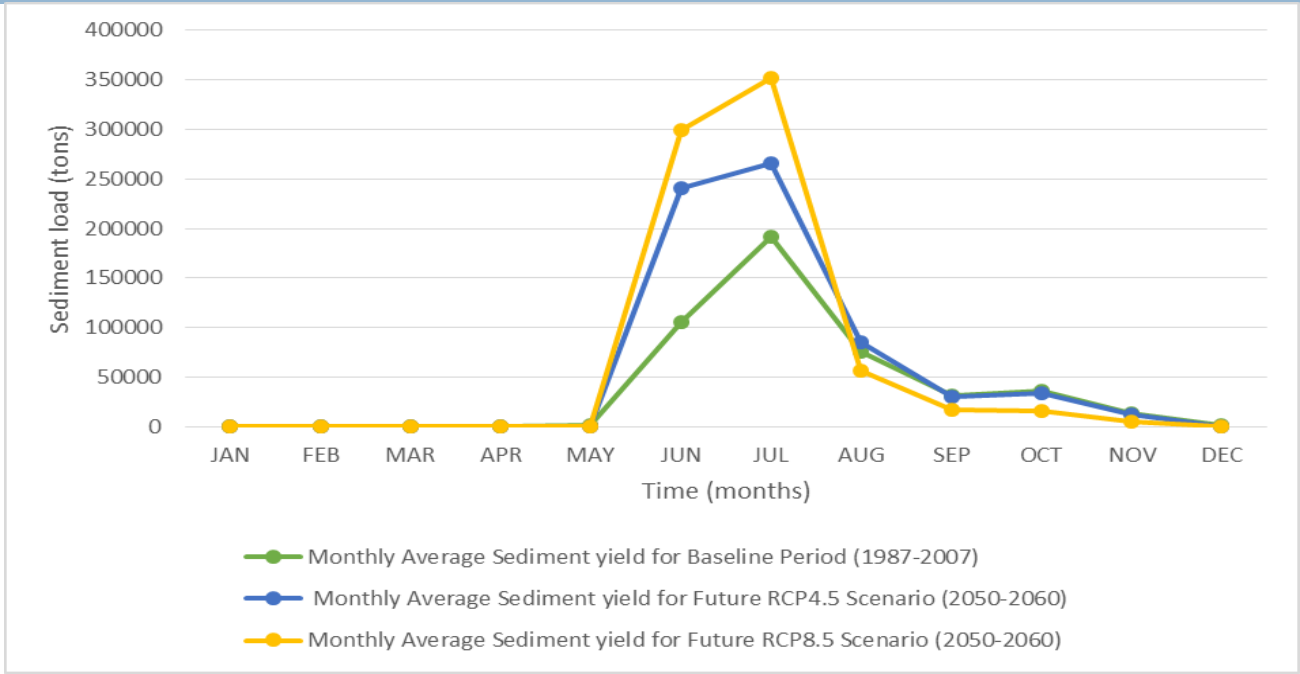


Fig. 16: Plot of monthly average sediment yield for baseline period and under the RCP scenarios

Contd …..

Table 3: Variation of streamflow and sediment yield under RCP 4.5 and RCP 8.5

Variable	RCP4.5			RCP8.5		
	January to May	June to August	September to December	January to May	June to August	September to December
Precipitation	-59.98 %	21.96%	-15.11%	-60.38%	38.35%	-31.34%
Maximum temperature	2.9ºC	2ºC	2ºC	3ºC	2.5ºC	2.5ºC
Minimum temperature	2.5ºC	0.5ºC	1ºC	3ºC	2ºC	2ºC
Relative humidity	-1.35%	-0.16%	-0.475%	-2.18%	-0.178%	-1.18%
Solar radiation	1%	-5.18%	4.24%	0.193%	-2.036%	3.67%
Streamflow	-52.57%	30.63%	-18.53%	-60.57%	44.79%	-18.53%
Sediment yield	-63.72%	56.18%	-33.52%	-81.11%	79.38%	-33.52%

Conclusions

- Seasonal variation in sediment yield for the decade 2050-2060 under climate change is analysed
- Under the climate change scenarios RCP4.5 and RCP8.5 projections show that maximum and minimum temperatures would increase in all seasons and precipitation would increase during south west monsoon and decrease during other seasons
- Variation is more in RCP8.5 when compared to RCP4.5

Contd…

- The variation in climate variables are strong enough to cause considerable variation in streamflow and sediment yield in the river basin
- Both streamflow and sediment yield would increase during southwest monsoon and decrease in all other seasons

Suggestions for effective watershed management

- Sediment yield during the monsoon period is likely to increase due to increase in precipitation and the resulting overland flow under both the RCPs considered
- As a corrective measure, upstream erosion control programs has to be initiated in the watershed
- Implementation of proper landuse practices over the basin will help to reduce soil erosion

Contd.....

- Increasing the vegetative cover in the watershed and maintaining a broad strip of riparian vegetation provides long term protection against erosion by protecting the soil against direct raindrop impact and enhances the infiltration rate
- Sediment detention basins can be constructed in the watershed to trap suspended sediments for water quality control and for protecting downstream aquatic environments
- Check dams can be constructed in the river to trap bed load and to prevent bed degradation

Contd.....

- Implementation of adaptation measures require awareness of the impacts of climate change among governmental and non-governmental bodies as well as the general public
- Resources and finance should be made available to implement appropriate management strategies

References

- Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., & Srinivasan, R. (2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *Journal of hydrology*, *333*(2), 413-430.
- Adem, A. A., Tilahun, S. A., Ayana, E. K., Worqlul, A. W., Assefa, T. T., Dessu, S. B., & Melesse, A. M. (2016). Climate Change Impact on Sediment Yield in the Upper Gilgel Abay Catchment, Blue Nile Basin, Ethiopia. In *Landscape Dynamics, Soils and Hydrological Processes in Varied Climates* (pp. 615-644). Springer International Publishing.
- Anandhi, A., Srinivas, V. V., Nanjundiah, R. S., & Nagesh Kumar, D. (2008). Downscaling precipitation to river basin in India for IPCC SRES scenarios using support vector machine. *International Journal of Climatology*, *28*(3), 401-420.
- Azari, M., Moradi, H. R., Saghafian, B., & Faramarzi, M. (2016). Climate change impacts on streamflow and sediment yield in the North of Iran. *Hydrological Sciences Journal*, *61*(1), 123-133.
- Azim, F., Shakir, A. S., & Kanwal, A. (2016). Impact of climate change on sediment yield for Naran watershed, Pakistan. *International Journal of Sediment Research*, *31*(3), 212-219.

Contd…..

- Bergström, S., Carlsson, B., Gardelin, M., Lindström, G., Pettersson, A., &Rummukainen, M. (2001). Climate change impacts on runoff in Sweden assessments by global climate models, dynamical downscaling and hydrological modelling. Climate research, 16(2), 101-112
- Fowler, D., Cape, J. N., Coyle, M., Flechard, C., Kuylenstierna, J., Hicks, K & Stevenson, D. (1999). The global exposure of forests to air pollutants. In Forest growth responses to the pollution climate of the 21st century (pp. 5-32). Springer Netherlands.
- Ghosh, S. (2010). SVM-PGSL coupled approach for statistical downscaling to predict rainfall from GCM output. *Journal of Geophysical Research: Atmospheres*, *115*(D22).
- Graves, D., & Chang, H. (2007). Hydrologic impacts of climate change in the Upper Clackamas River Basin, Oregon, USA.
- Green, W. H., & Ampt, G. A. (1911). Studies on Soil Phyics. *The Journal of Agricultural Science*, *4*(01), 1-24.
- Li, T., & Gao, Y. (2015). Runoff and Sediment Yield Variations in Response to Precipitation Changes: A Case Study of Xichuan Watershed in the Loess Plateau, China. *Water*, *7*(10), 5638-5656.

Contd…..

- Ndomba, P. M., Mtalo, F. W., & Killingtveit, A. (2008). A guided swat model application on sediment yield modeling in pangani river basin: lessons learnt.
- Raghavan, S. V., Vu, M. T., & Liong, S. Y. (2012). Assessment of future stream flow over the Sesan catchment of the Lower Mekong Basin in Vietnam. *Hydrological Processes*, *26*(24), 3661-3668.
- Shrestha, B., Babel, M. S., Maskey, S., Van Griensven, A., Uhlenbrook, S., Green, A., & Akkharath, I. (2013). Impact of climate change on sediment yield in the Mekong River basin: a case study of the Nam Ou basin, Lao PDR. *Hydrology and Earth System Sciences*, *17*(1), 1.
- Swami, V. A., & Kulkarni, S. S. (2016). Simulation of Runoff and Sediment Yield for a Kaneri Watershed Using SWAT Model. *Journal of Geoscience and Environment Protection*, *4*(01), 1.
- Van Wambeke, A., & Newhall, F. (1981). Calculated soil moisture and temperature regimes of South America: a compilation of soil climatic regimes calculated by using a mathematical model developed by F. Newhall (Soil Conservation Service, USDA, 1972). *SMSS technical monograph (USA). no. 2.*
- Wilby, R. L., & Dawson, C. W. (2013). The statistical downscaling model: insights from one decade of application. *International Journal of Climatology*, *33*(7), 1707-1719.
- Williams, J. R., & Berndt, H. D. (1976). Sediment yield prediction based on watershed hydrology. American Society of Agricultural Engineering.

Thank you ..