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

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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 century.

This can cause variation in the timing, intensity and frequency of precipitation events.
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
Chaliyar river basin, Kerala, India
- Chaliyar - the fourth longest river (169km) in Kerala, India
- Area of the river basin in Kerala is 2530km²
- 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)
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

HYDROLOGICAL MODEL

CALIBRATION
VALIDATION

FUTURE CLIMATE PROJECTIONS
(Precipitation, Temperature, Relative Humidity, Solar Radiation)

PROJECTION OF FUTURE SEDIMENT YIELD

SUGGESTION OF MANAGEMENT MEASURES

Fig 4: Overall methodology adopted in the study
# Hydrological model SWAT

- For modeling purposes, a watershed is partitioned into a number of subbasins.
- 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.
Water Balance Equation

\[ SW_t = SW_0 + \sum_{i=1}^{t} (R_{\text{day}} - Q_{\text{surf}} - E_a - w_{\text{sweep}} - Q_{gw})i \] .................(1)

- \( SW_t \) is the final soil water content,
- \( SW_0 \) is the initial soil water content on day \( i \) (mm),
- \( R_{\text{day}} \) is the amount of precipitation on day in mm,
- \( Q_{\text{surf}} \) is the amount of surface runoff on day \( i \) in mm,
- \( E_a \) is the amount of evapotranspiration on day \( i \) in mm,
- \( w_{\text{sweep}} \) 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 runoff is by SCS curve number (CN) method

\[ Q = \frac{(R - 0.2S)^2}{R + 0.2S} \quad \ldots \ldots \quad \text{(2)} \]

\[ S = 25.4 \left( \frac{1000}{CN} - 10 \right) \quad \ldots \ldots \quad \text{(3)} \]

- \( Q \) = Daily surface runoff (mm)
- \( R \) = Daily rainfall (mm)
- \( S \) = Retention parameter
- \( CN \) = Curve number ranging from 0 to 100
The Modified Universal Soil Loss Equation (MUSLE) estimates the erosion produced by both rainfall and surface runoff flow for each single rain storm.

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

- \( Q_{SED} \) is the yield 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),
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**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
<th>Scale</th>
<th>Data description/ properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Survey of India</td>
<td>1:50000</td>
<td>Elevation, spot height, drainage, boundary</td>
</tr>
<tr>
<td>Landuse</td>
<td>Kerala State Landuse Board</td>
<td>1:50000</td>
<td>Land-use classification such as croplands, forests and pastures</td>
</tr>
<tr>
<td>Soil</td>
<td>Kerala State Landuse Board</td>
<td>1:250000</td>
<td>Soil classification and physical properties</td>
</tr>
</tbody>
</table>
# Input Data and Source

<table>
<thead>
<tr>
<th></th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weather</strong></td>
<td><strong>Meteorological observatory of the CWRDM at Kottamparamba</strong></td>
<td>Daily precipitation, Maximum and minimum temperature (1982-2007)</td>
</tr>
<tr>
<td><strong>Streamflow and sediment</strong></td>
<td><strong>Gauging station of the CWC at Kuniyil</strong></td>
<td>Daily discharge, sediment concentration (1982-2007),</td>
</tr>
<tr>
<td><strong>Future climate data</strong></td>
<td><strong>CORDEX IITM</strong></td>
<td>Dynamically downscaled data for RCP4.5 and RCP8.5 from REMO 2009 (MPI) (MPI Regional model 2009). Driving GCM MPI-ESM-LR</td>
</tr>
</tbody>
</table>
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
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
Table 2: Parameters used for calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Fitted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V__SPCON.bsn</td>
<td>Linear re-entrainment parameter for channel sediment routing</td>
<td>0.00035</td>
</tr>
<tr>
<td>V__SPEXP.bsn</td>
<td>Exponent parameter for calculating sediment reentrained in channel sediment routing</td>
<td>0.35</td>
</tr>
<tr>
<td>V__USLE_C.crop.dat</td>
<td>USLE land cover factor</td>
<td>0.1</td>
</tr>
<tr>
<td>V__USLE_P.mgt</td>
<td>USLE equation support practice</td>
<td>0.15</td>
</tr>
<tr>
<td>V__CH_COV2.rte</td>
<td>Channel cover factor</td>
<td>0.25</td>
</tr>
<tr>
<td>V__CH_COV1.rte</td>
<td>Channel erodibility factor</td>
<td>0.25</td>
</tr>
<tr>
<td>V__SLSUBBSN.hru</td>
<td>Average slope length</td>
<td>50</td>
</tr>
<tr>
<td>R__ALPHA_BF.gw</td>
<td>Baseflow alpha factor</td>
<td>0.5</td>
</tr>
<tr>
<td>V__CH_N2.rte</td>
<td>Manning’s n-value for main channel</td>
<td>0.20</td>
</tr>
<tr>
<td>R__SOL_AWC.sol</td>
<td>Available water capacity (mm mm−1 soil)</td>
<td>0.25</td>
</tr>
<tr>
<td>V__ESCO.bsn</td>
<td>Soil evaporation compensation factor</td>
<td>0.5</td>
</tr>
<tr>
<td>V__CN2.mgt</td>
<td>Curve number</td>
<td>84</td>
</tr>
</tbody>
</table>
Fig. 9: Comparison of observed vs. predicted sediment yield for the calibration period

$R^2 = 0.68$

$NSE = 0.64$
Validation

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

$R^2 = 0.70$

$NSE = 0.67$
Climate Model and Bias Correction

RCM - REMO2009
- Resolution $0.5^\circ \times 0.5^\circ$
- 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
• Multiplicative correction is applied for precipitation, relative humidity, (eqns. 5 and 6)

\[ P^*_\text{cont}(d) = P_{\text{obs}}(d) \]  
\[ P^*_{\text{scen}}(d) = P_{\text{obs}}(d) \times \frac{\mu_m(P_{\text{scen}}(d))}{\mu_m(P_{\text{cont}}(d))} \]

\[ T^*_\text{cont}(d) = T_{\text{obs}}(d) \]  
\[ T^*_{\text{scen}}(d) = T_{\text{obs}}(d) + \mu_m(T_{\text{scen}}(d) - T_{\text{cont}}(d)) \]
where

- $\mu_m$ is the mean within the monthly interval
- $P^*_{\text{cont}}(d)$ is the final bias corrected precipitation in the control period (RCM simulated),
- $P_{\text{obs}}(d)$ is the observed daily precipitation,
- $P_{\text{scen}}(d)$ is the daily precipitation while considering the scenario period of the climate model,
- $P^*_{\text{scen}}(d)$ is the final bias corrected daily precipitation during the scenario period,
- $T^*_{\text{cont}}(d)$ is the final bias corrected temperature,
- $T_{\text{obs}}(d)$ is the observed daily temperature,
- $T_{\text{scen}}(d)$ is the daily temperature while considering the scenario period of the climate model,
- $T^*_{\text{scen}}(d)$ is the final bias corrected daily temperature during the scenario period
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.
Fig. 11: Plot of monthly average precipitation for the baseline period and under the RCP scenarios
Fig. 12. Plot of monthly average maximum temperature for the baseline period and under the RCP scenarios
Fig. 13: Plot of monthly average minimum temperature for the baseline period and under the RCP scenarios.
Fig. 14: Plot of monthly average of relative humidity for the baseline period and under the RCP scenarios.
Fig. 15: Plot of monthly average of solar radiation for baseline period and under the RCP scenarios.
Fig. 16: Plot of monthly average sediment yield for baseline period and under the RCP scenarios
Table 3: Variation of streamflow and sediment yield under RCP 4.5 and RCP 8.5

<table>
<thead>
<tr>
<th>Variable</th>
<th>RCP4.5</th>
<th>RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>January to May</td>
<td>June to August</td>
</tr>
<tr>
<td>Precipitation</td>
<td>-59.98%</td>
<td>21.96%</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>2.9°C</td>
<td>2.0°C</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>2.5°C</td>
<td>0.5°C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>-1.35%</td>
<td>-0.16%</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>1%</td>
<td>-5.18%</td>
</tr>
<tr>
<td>Streamflow</td>
<td>-52.57%</td>
<td>30.63%</td>
</tr>
<tr>
<td>Sediment yield</td>
<td>-63.72%</td>
<td>56.18%</td>
</tr>
</tbody>
</table>
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.
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.
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.


Thank you ..