Exploring Adaptation Options to Climate Change in Semi-Arid Watershed Using Choice of BMPs

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Motivation

- An integrated management plan is required to prevent the negative impacts of climate change on social-economic and environment aspects.
- Each of these segments is expected to be strongly impacted by climate change.
- Impact assessment of climate change on water resources and its adaptation are of primary concern and interest.
- Adaptation is response to climate change to seek possibilities and/or capabilities to impacts.
- Climate change adaptation can be improved by i) adjusting exposure ii) reducing sensitivity of the system to climate change impacts and iii) enhancing the system adaptive capacity.
- The present study has been conducted to explore adaptation options (BMPs) to address implications on account of climate change impacts in Karkheh River Basin.
Study Area

- The KRB is located in the western part of Iran. The drainage area of the basin is about 50,764 km$^2$, out of which 80% falls in the Zagros mountain ranges.

- The topography depicts large spatial variation with elevations ranging from 3 to more than 3,500 masl. The elevation of about 60% of the basin area is 1,000-2,000 masl and about 20% is below 1,000 masl.

- The precipitation (P) pattern depicts large spatial and intra-and inter-annual variability across the basin. The mean annual precipitation ranges from 150 mm/yr. in the lower arid plains to 750 mm/yr. in the mountainous parts.
Study Area

LULC

The rain-fed farming, rangelands, forests and irrigated farming are the main land use types. The rain-fed farming and rangelands are mainly scattered throughout the mountainous region with varying degrees of coverage. Forested areas are mainly found in middle parts of the basin. Most of the irrigated farming is concentrated in the lower region (Lower KRB) and in the upper northern regions (Gamasiab sub-basin). The cultivated area account for about 25 percent of the total area, which comprises of rain-fed and irrigated farming areas.
Model Setup

• The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of 90 m resolution was used for sub-basin definition (49 sub-basin)

• The land use map was prepared using fine resolution Landsat ETM+(2002)

• The soil map was obtained from the global soil map of the FAO (1995)

• Daily climatic data for the period from January 1982 to December 2005 were used for the model simulations (Precipitation and temperature data from 10 synoptic stations)

• Daily discharge data for 24 stages (1982 to 2005); gives us the possibility for each sub-basin
Sensitivity Analysis

- It is the prior step to model calibration to demonstrate the impact that change to an individual input parameter has on the model response and can be performed using a number of different methods.

- The method in the Arc-SWAT Interface combines the Latin Hypercube (LH) and One-factor-At-a-Time (OAT) sampling and the sensitivity analysis tool has the capability of performing two types of analyses:
  
  - The first type of analysis uses only modelled data to identify the impact of adjusting a parameter value on some measure of simulated output, such as average stream-flow.
  - The second type of analysis uses measured data to provide overall “goodness of fit” estimation between the modelled and the measured time series.

- The first analysis may help to identify parameters that improve a particular process or characteristic of the model, while the second analysis identifies the parameters that are affected by the characteristics of the study watershed and those to which the given project is most sensitive (Veith and Ghebremichael, 2009).
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Description</th>
<th>Initial value</th>
<th>Rank No. *</th>
<th>Rank No. **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALPHA_BF</td>
<td>Baseflow alpha factor (Days)</td>
<td>0-50</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>CANMX</td>
<td>Maximum canopy storage (mmH$_2$O)</td>
<td>0-10</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>CH_K2</td>
<td>Channel Effective Hydraulic Conductivity</td>
<td>0-150</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>CH_N2</td>
<td>Manning Coefficient for Channel</td>
<td>0.01-0.3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>CN2</td>
<td>Initial SCS Runoff Curve number for Wetting Condition-2</td>
<td>±20%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>EPCO</td>
<td>Plant uptake compensation factor</td>
<td>0-1</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>ESCO</td>
<td>Soil Evaporation Compensation Factor</td>
<td>0-1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>GW_DELAY</td>
<td>Ground Water Delay Time</td>
<td>0-50</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>GW_REVAP</td>
<td>Ground Water &quot;REVAP&quot; Coefficient</td>
<td>0.02-0.2</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>GWQMN</td>
<td>Threshold Depth for shallow aquifer for flow</td>
<td>0-5000</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>RCHRG_DP</td>
<td>Deep Aquifer Percolation Factor</td>
<td>0-1</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>REVAPMN</td>
<td>Threshold Depth of water in shallow aquifer for &quot;REVAP&quot;</td>
<td>0-500</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>13</td>
<td>SFTMP</td>
<td>Snowfall temperature (°C)</td>
<td>-5-5</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>SLOPE</td>
<td>Slope steepness (m/m)</td>
<td>0-0.6</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>15</td>
<td>SMFMN</td>
<td>Melt factor for snow December 21 (MM H$_2$O/°C-day)</td>
<td>0-10</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>SMFMX</td>
<td>Melt factor for snow June 21 (mm H$_2$O/°C-day)</td>
<td>0-10</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>17</td>
<td>SMTMP</td>
<td>Snow melt base (°C)</td>
<td>-5-5</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>SOL_AWC</td>
<td>Soil Available Water Capacity</td>
<td>0.01-0.5</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>19</td>
<td>SURLAG</td>
<td>Surface Runoff Lag Time</td>
<td>0-10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>TIMP</td>
<td>Snow pack lag temperature lag factor</td>
<td>0-1</td>
<td>12</td>
<td>9</td>
</tr>
</tbody>
</table>

*without observed data - **with observed data
Calibration and Validation

- For this study, manual approach has been used for calibration/ validation (Based on daily time steps data) (Solaymani and Gosain, 2012):
  - The manual and (One-factor-At-a-Time (OAT) sampling has been used)
- For evaluation of Calibration the below methods has been chosen:
  - Graphical Procedure
  - Statistical Methods
    - Nash–Sutcliffe Efficiency (NSE)
    - Percent Bias (PBIAS)
    - And observations standard deviation ratio (RSR)
Graphical Model Evaluation

Based on the Moriasi et al (2007) and Singh et al (2004); they had recommended the third value (RSR) for better performance for calibration evaluation

General performance ratings for recommended statistical parameters for a monthly time step (Moriasi et Al, 2007)

<table>
<thead>
<tr>
<th>Performance Rating</th>
<th>NSE</th>
<th>PBIAS</th>
<th>RSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>0.75&lt;NSE&lt;1.00</td>
<td>PBIAS&lt;±10</td>
<td>0.00&lt;RSR&lt;0.50</td>
</tr>
<tr>
<td>Good</td>
<td>0.65&lt;NSE&lt;0.75</td>
<td>±10&lt;PBIAS&lt;±15</td>
<td>0.50&lt;RSR&lt;0.60</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0.60&lt;NSE&lt;0.65</td>
<td>±15&lt;PBIAS&lt;±25</td>
<td>0.60&lt;RSR&lt;0.70</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>NSE≤0.50</td>
<td>PBIAS≥±25</td>
<td>RSR≥0.70</td>
</tr>
</tbody>
</table>

The next step was to calculate values for NSE, PBIAS, and RSR. With these values, model performance can be judged based on general performance ratings

Outputs for statistical parameters with manual calibration and auto-calibration at Pay-e-Pol flow gauge station (Daily-Base data)

<table>
<thead>
<tr>
<th>Approach</th>
<th>NSE</th>
<th>PBIAS</th>
<th>RSR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration</td>
<td>Validation</td>
<td>Calibration</td>
</tr>
<tr>
<td>Manual Calibration</td>
<td>0.71 (Good)</td>
<td>0.60 (Satisfactory)</td>
<td>-0.24 (Very good)</td>
</tr>
<tr>
<td>Auto-calibration</td>
<td>0.31 (Unsatisfactory)</td>
<td>0.32 (Unsatisfactory)</td>
<td>30.7 (Unsatisfactory)</td>
</tr>
</tbody>
</table>
Statistical Evaluation

Also it should be noted that the time step which was used for the performance analysis was daily. It was also decided to check the impact of the choice of interval on the performance of the model. Thus, performance was computed again by taking the interval as monthly and the results are shown.

Outputs for statistical parameters with manual calibration and auto-calibration at Pay-e-Pol flow gauge station (Using monthly data)

<table>
<thead>
<tr>
<th>Approach</th>
<th>NSE</th>
<th>PBIAS</th>
<th>RSR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration</td>
<td>Validation</td>
<td>Calibration</td>
</tr>
<tr>
<td>Manual Calibration</td>
<td>0.91 (Very</td>
<td>0.85 (Very</td>
<td>-0.001 (Very</td>
</tr>
<tr>
<td></td>
<td>good)</td>
<td>good)</td>
<td>good)</td>
</tr>
<tr>
<td>Auto-calibration</td>
<td>0.31 (Unsatisfactory)</td>
<td>0.32 (Unsatisfactory)</td>
<td>0.002 Very good)</td>
</tr>
</tbody>
</table>

It may be observed from the above table that overall the performance with respect to all the parameters have improved by taking the monthly interval. The overall performance under the “Manual calibration” for both calibration and validation period has improved to “Very good”. The results under the “Auto-calibration” approach has also improved in comparison to the daily interval for some of the individual statistical parameters, for both calibration and validation time steps. However, the overall performance under “Auto-calibration” does not improve and remain “Unsatisfactory” to be on the conservative side.
In this study, scenarios from REMO and PRECIS regional climate models (RCMs) have been used. The A1B emission scenario for REMO and A2 and B2 emission scenarios for PRECIS have been applied. Analysis of climate change projection was made using two major parameters of temperature and precipitation influencing water resources.

- Monthly and annual mean daily maximum and mean daily minimum temperature for REMO (with A1B scenario) and PRECIS (with A2 and B2 scenarios) RCM models have been used.

### Precipitation

Precipitation long-term values in end century (2070-2099) along with baseline (1970-1999) (triangles). The box-whisker plot (median, 25th and 50th percentiles and minimum and maximum) are given for PRECIS (A2&B2) and REMO (A1B)
Long-term monthly temperature (average maximum and minimum daily) values for the end century (2070-2099) along with baseline (1970-1999) (triangles). The box-whisker plot (median, 25th and 50th percentiles and minimum and maximum) are given for PRECIS (A2&B2) and REMO (A1B). (a), (b) and (c) show monthly values of average maximum temperature under A2, B2 and A1B emission scenarios. (d), (e) and (f) show monthly values of average minimum temperature under A2, B2 and A1B emission scenarios.
Crop (Wheat) Yield

1) Baseline

2) A1B

3) A2

4) B2

Rain-fed

Irrigated

5) Baseline

6) A1B

7) A2

8) B2
Best Management Practices (BMPs)

- BMPs are those field operations which promote efficient use of resources, safety for stakeholders, and sustainable management of water resources. They are often used to control the runoff, sediments and nutrients as non-point source hazards.
- The choice of the BMPs will vary from watershed to watershed due to varying characteristics.
- BMPs can be as structural and non-structural. Various BMPs are usually combined together in the watershed.
- SWAT model allows using detailed management practices mainly on cultivated lands. It has wide spectrum of abilities to manage the cultivation field operations.
- In order to evaluate the general performances of choice of BMPs, SWAT was applied to Karkheh River Basin (KRB).
Choice of Best Management Practices (BMPs)

- The options being explored are in the form of best management practices (BMPs) that can account for the deficit in water availability through proper selection and deployment of suitable BMPs.
- Four of the BMPs have been selected for this study. These are Terracing, Contouring, Strip Cropping, and Grade Stabilization Structure (GSS).
  - Terracing
    Terracing is highly used to decrease the peak flow, soil surface erosion, keeping the soil moisture and water quality improvement (USEPA, 2004). Various parameters affected by terracing include CN2, SLSUBASIN (sub-basin average slope length), and USLE_P (USLE practice factor)
  - Contouring
    Contouring is the tillage practice for planting the crops aligned to terrain contours. It enhances surface detention and reduces erosion, runoff and evaporation. SWAT simulates this operation by altering CN2 to increase the surface storage and USLE_P to decrease soil surface erosion
  - Strip cropping
    Strip cropping is a band arrangement of crops that is mainly use on steep slopes. It is incorporated by adjusting STRIP_N (Manning coefficient for overland flow), CN2, STRIP_C (USLE cropping factor) in SWAT
  - GSS
    GSS is addressed through the structures to reduce streams and waterways slopes in natural or artificial water course. It reduces the water speed to store runoff and stabilize the grade to trap the sediments. There are some example of GSS as chutes, vertical drops, weir spillways and checkdams.
The selected BMPs are incorporated in the cultivated portions of the KRB. The results of deployment of suitable BMPs for the deficit in water availability under different scenarios have been discussed under two scenarios:

- **Evaluation on baseline climate condition (1970-1999)**
  The choice of BMPs was simulated on baseline conditions to evaluate the impacts on some major hydrologic components such as surface runoff, groundwater, and sediments yield. Terracing and strip cropping have been modelled on cultivated lands in Upper and Middle KRB due to mountainous terrain conditions. Terracing was simulated on irrigated cultivated lands due to expense of terracing in high slopes and the location of the cultivated land on the upper range in KRB. The GSS have been modelled mainly on rangelands because of their ownerships.

- **Evaluation on future climate condition (2070-2099)**
  Using the knowledge on the impacts due to the management practices under the present scenario, choice has been made to identify some suitable practices to circumvent the effects of the climate change.
## Evaluation on baseline climate condition (1970-1999)

### Comparison of selected BMPs on some hydrologic components on baseline in KRB

<table>
<thead>
<tr>
<th>Basin</th>
<th>Management Application</th>
<th>Surface water (mm)</th>
<th>Ground water (mm)</th>
<th>Total sediment (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper KRB</td>
<td>No application</td>
<td>63.20</td>
<td>33.56</td>
<td>8.80</td>
</tr>
<tr>
<td></td>
<td>Terracing</td>
<td>14.05</td>
<td>48.35</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Strip cropping</td>
<td>NCC*</td>
<td>NCC</td>
<td>NCC</td>
</tr>
<tr>
<td></td>
<td>Contouring</td>
<td>11.8</td>
<td>67.83</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>GSS**</td>
<td>53.10</td>
<td>9.09</td>
<td>-</td>
</tr>
<tr>
<td>Middle KRB</td>
<td>No application</td>
<td>125.76</td>
<td>62.71</td>
<td>18.93</td>
</tr>
<tr>
<td></td>
<td>Terracing</td>
<td>18.98</td>
<td>152.03</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>Strip cropping</td>
<td>NCC</td>
<td>NCC</td>
<td>NCC</td>
</tr>
<tr>
<td></td>
<td>Contouring</td>
<td>23.52</td>
<td>127.67</td>
<td>2.26</td>
</tr>
<tr>
<td></td>
<td>GSS</td>
<td>44.24</td>
<td>17.06</td>
<td>-</td>
</tr>
</tbody>
</table>

*NCC-No Considerable Change in compare to” No application”  ** GSS-Graded Stabilization Structure
### Evaluation on future climate condition (2070-2099)

Comparison of surface flow (m$^3$/sec) analysis with selected BMPs on climate change projections and baseline information in KRB

<table>
<thead>
<tr>
<th>Basin</th>
<th>BMPs</th>
<th>Statistic Results</th>
<th>Baseline condition</th>
<th>Climate Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>Upper KRB</td>
<td>No application</td>
<td>46.65</td>
<td>718</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>With application</td>
<td>50.63</td>
<td>323.1</td>
<td>6.16</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>76.65</td>
<td>709.2</td>
<td>33.45</td>
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<tr>
<td></td>
<td>Min</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Middle KRB</td>
<td>No application</td>
<td>146.28</td>
<td>1647</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>With application</td>
<td>147.67</td>
<td>915.20</td>
<td>10.11</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>127.61</td>
<td>1174</td>
<td>217.1</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Evaluation on future climate condition (2070-2099)

- Implementation of appropriate BMPs can influence the local hydrology by regulating the maximum and minimum flow values range. The more important point in implementation of BMPs is their role in reducing the extreme conditions.
Conclusions

- SWAT model allows using detailed management practices to manage the cultivation field operations

- The effect of selected BMPs has been examined to circumvent the impacts of climate change under the future ‘PRECIS’ and ‘REMO’ regional climate models dynamically downscaled from the latest GCMs

- The impact of selected BMPs had various effects on the major hydrological components e.g. surface runoff, groundwater and sediment erosion

- Amongst the selected BMPs, terracing followed by GSS has been found to influence significantly on selected hydrologic components and Strip cropping has been found to be less effective.

- Results of this study show that integrated water resources management should be used to analyse various possible BMPs comparatively
Thank you for your attention

For further questions and suggestion please contact!
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