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

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Motivation

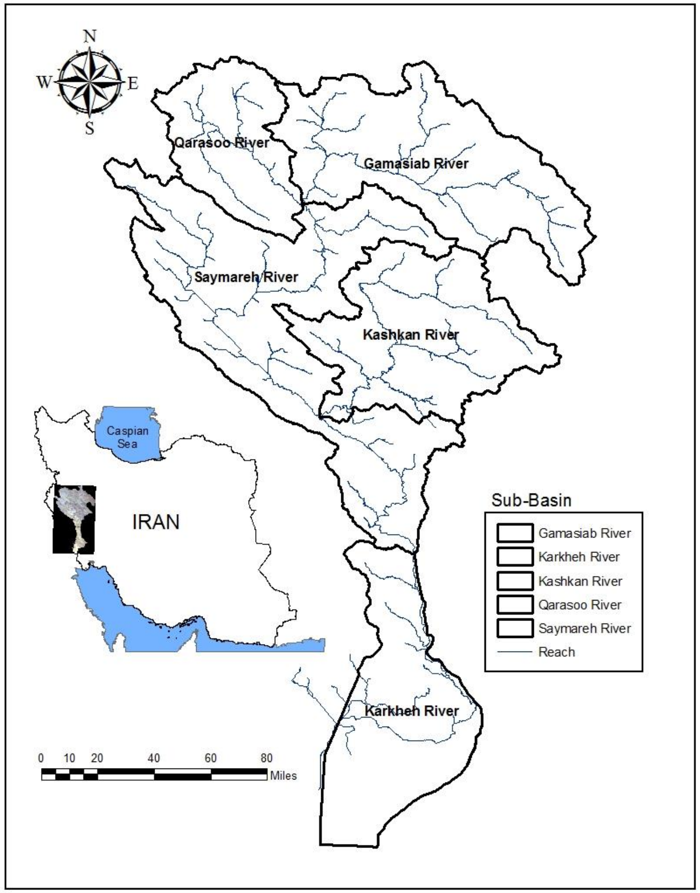
- An integrated management plan is required to prevent the negative impacts of climate change on social- economic and environment aspects
- Each of these segments is expected to be strongly impacted by climate change
- Impact assessment of climate change on water resources and its adaptation are of primary 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

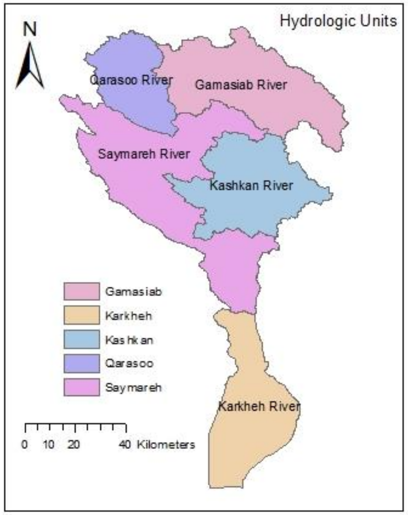
• The precipitation (P) pattern depicts large spatial and intra-and inter-annual variability across the basin. The mean annual precipitation ranges from 150 mm/yr. in the lower arid plains to 750 mm/yr. in the mountainous parts

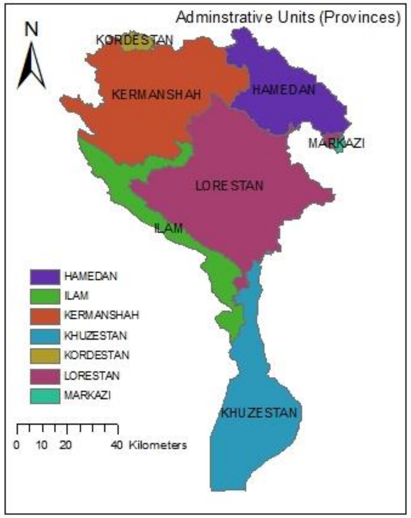


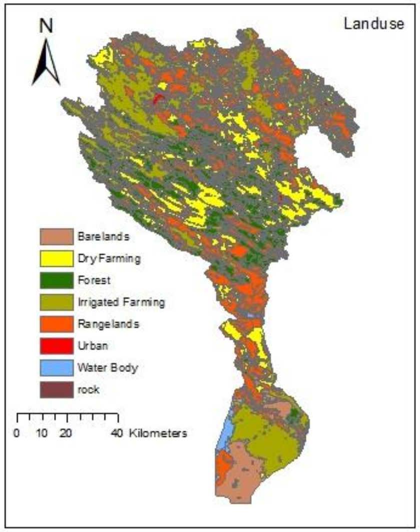
Study Area

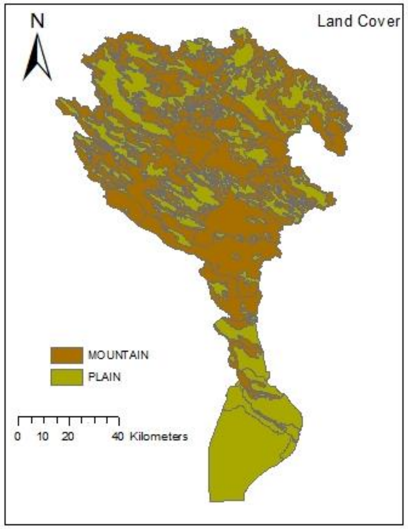
LULC

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

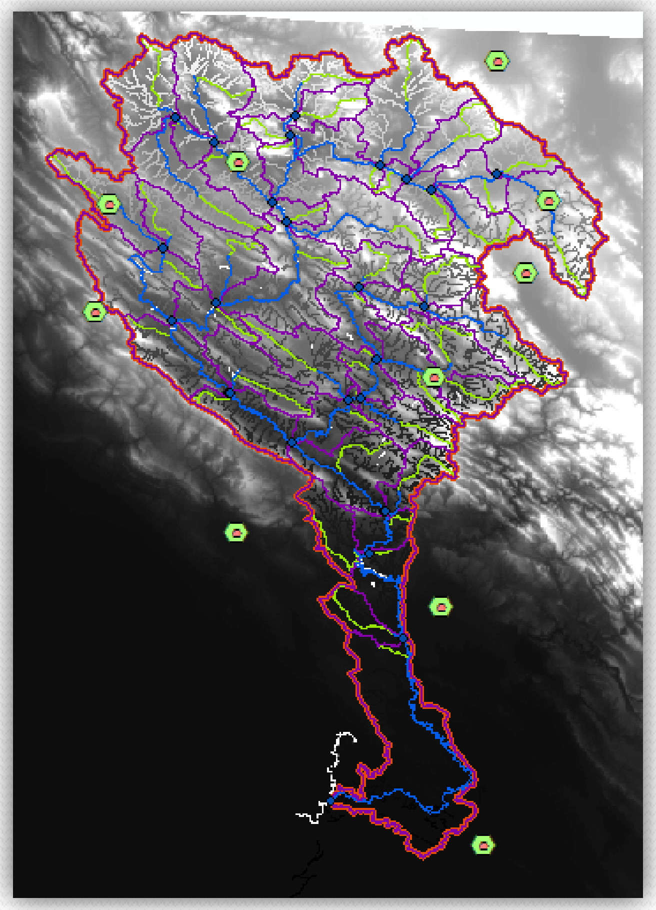
• The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of 90 m resolution was used for sub-basin definition (49 sub-basin)

• 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 demonstrates 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

No	Parameter	Description	Initial value	Rank No. *	Rank No. **
1	ALPHA_BF	Baseflow alpha factor (Days)	0-50	2	4
2	CANMX	Maximum canopy storage (mmH_2O)	0-10	10	16
3	CH_K2	Channel Effective Hydraulic Conductivity	0-150	4	15
4	CH_N2	Manning Coefficient for Channel	0.01-0.3	6	5
5	CN2	Initial SCS Runoff Curve number for Wetting Condition-2	±20%	1	1
6	EPCO	Plant uptake compensation factor	0-1	14	20
7	ESCO	Soil Evaporation Compensation Factor	0-1	3	3
8	GW_DELAY	Ground Water Delay Time	0-50	11	10
9	GW_REVAP	Ground Water "REVAP" Coefficient	0.02-0.2	15	19
10	GWQMN	Threshold Depth for shallow aquifer for flow	0-5000	13	2
11	RCHRG_DP	Deep Aquifer Percolation Factor	0-1	7	12
12	REVAPMN	Threshold Depth of water in shallow aquifer for "REVAP"	0-500	16	18
13	SFTMP	Snowfall temperature (°C)	-5-5	20	6
14	SLOPE	Slope steepness (m/m)	0-0.6	9	13
15	SMFMN	Melt factor for snow December 21 (MM H_2O/°C-day)	0-10	20	8
16	SMFMX	Melt factor for snow June 21 (mm H_2O/°C-day)	0-10	20	11
17	SMTMP	Snow melt base (°C)	-5-5	8	7
18	SOL _AWC	Soil Available Water Capacity	0.01-0.5	20	14
19	SURLAG	Surface Runoff Lag Time	0-10	5	5
20	TIMP	Snow pack lag temperature lag factor	0-1	12	9

*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)

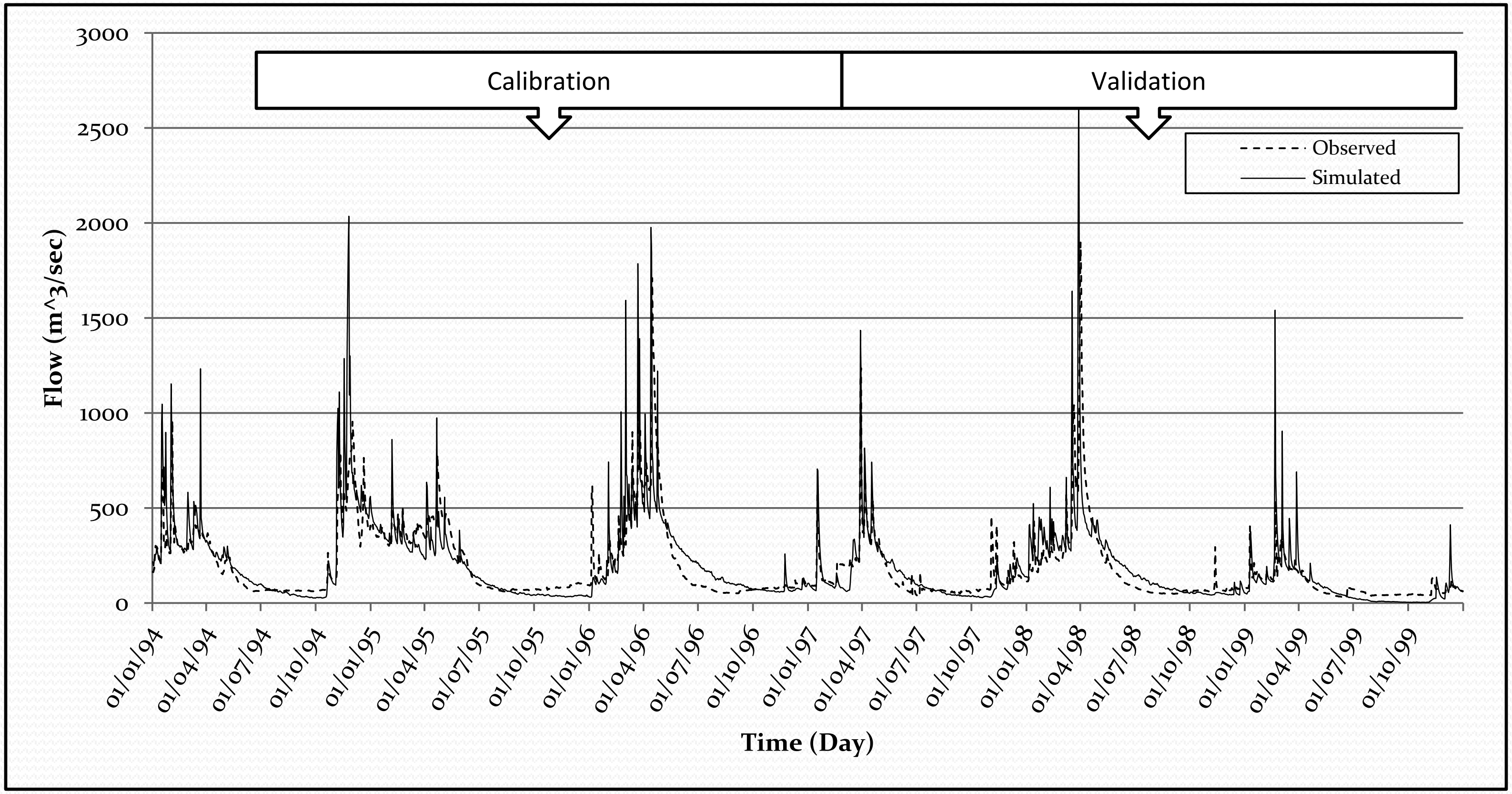
$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n} (Q_i^{obs} - Q_i^{mean})^2} \right]$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Q_i^{obs} - Q_i^{sim}) * 100}{\sum_{i=1}^{n} (Q_i^{obs})} \right]$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} (Q_i^{obs} - Q_i^{sim})^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} (Q_i^{obs} - Q_i^{avg})^2} \right]}$$

Graphical Model Evaluation

- Observed and simulated flow after manual calibration in Pay-e-Pol flow gauge station (Calibrated 1994 to 1996 and validated 1996 to 1999)



Statistical 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)

Performance Rating	NSE	PBIAS	RSR
Very good	0.75<NSE<1.00	PBIAS<±10	0.00<RSR<0.50
Good	0.65<NSE<0.75	±10<PBIAS<±15	0.50<RSR<0.60
Satisfactory	0.60<NSE<0.65	±15<PBIAS<±25	0.60<RSR<0.70
Unsatisfactory	NSE≤0.50	PBIAS≥±25	RSR≥0.70

- 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)

Approach	NSE		PBIAS		RSR	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
Manual Calibration	**0.71** (Good)	**0.60** (Satisfactory)	**-0.24** (Very good)	**0.96** (Very good)	**0.6** (Good)	**0.25** (Very good)
Auto-calibration	**0.31** (Unsatisfactory)	**0.32** (Unsatisfactory)	**30.7** (Unsatisfactory)	**0.50** (Very good)	**0.71** (Unsatisfactory)	**0.78** (Unsatisfactory)

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)

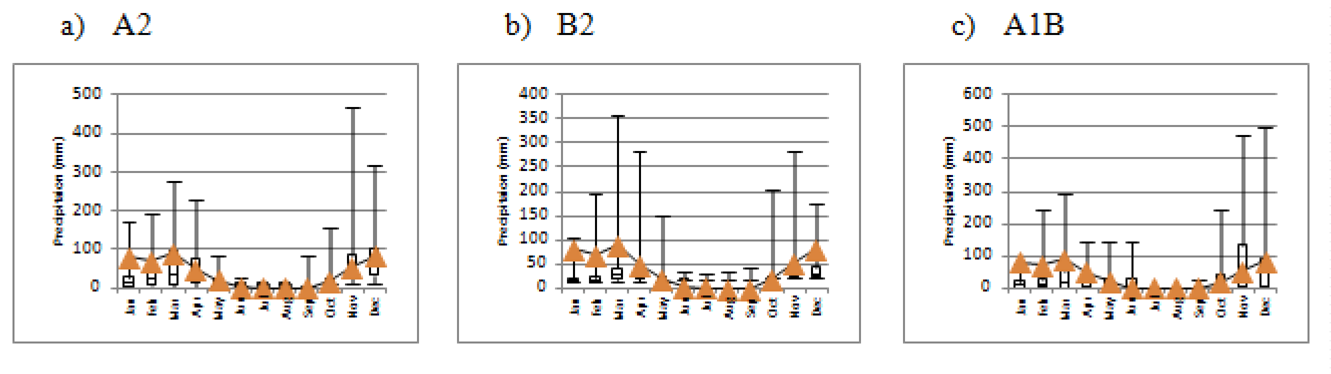
Approach	NSE		PBIAS		RSR	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
Manual Calibration	**0.91** (Very good)	**0.85** (Very good)	**-0.001** (Very good)	**0.07** (Very good)	**0.31** (Very good)	**0.39** (Very good)
Auto-calibration	**0.31** (Unsatisfactory)	**0.32** (Unsatisfactory)	**0.002** Very good)	**0.77** (Very good)	**1.14** (Unsatisfactory)	**0.63** (Satisfactory)

- 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.

Climate Change Projections

- 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.

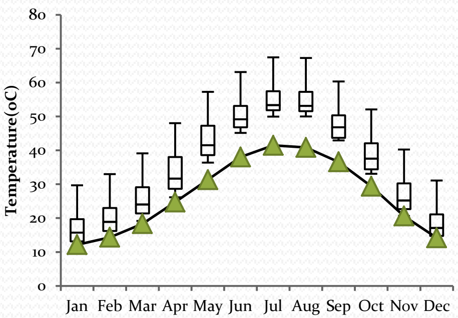
Precipitation



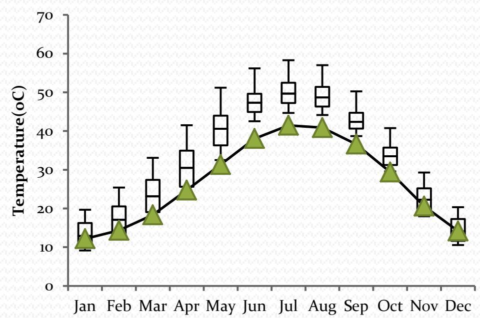
Precipitation long-term values in end century (2070-2099) along with baseline (1970-1999) (triangles). The box-whisker plot (median, 25th and 50th percentiles and minimum and maximum) are given for PRECIS (A2&B2) and REMO (A1B)

Temperature

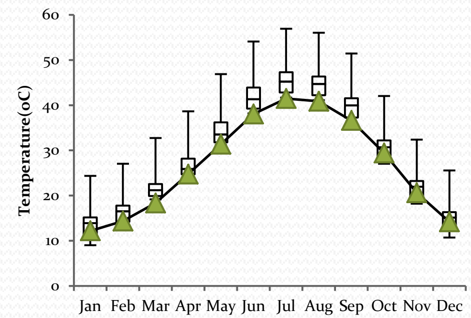
a) T_{max}-A2



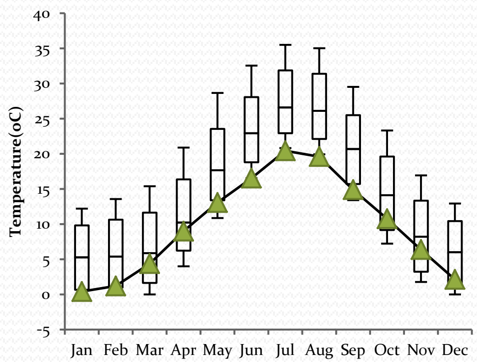
b) T_{max}-B2



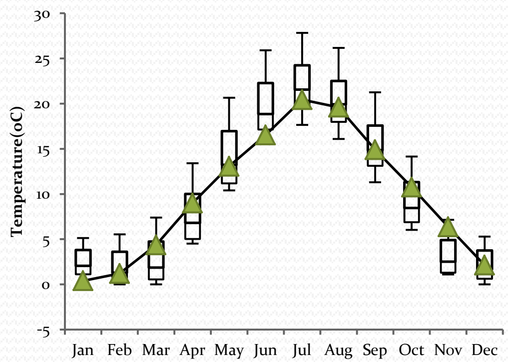
c) T_{max}-A1B



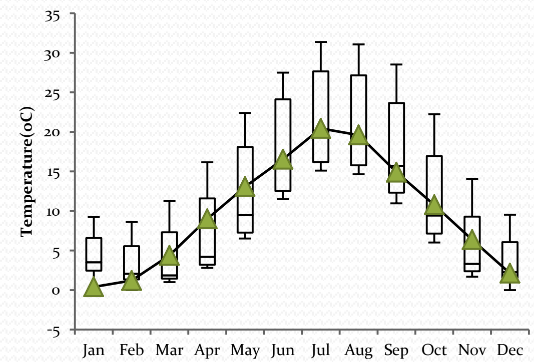
d) T_{min}-A2



e) T_{min}-B2



f) T_{min}-A1B

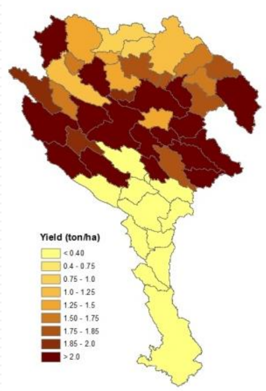


Long-term monthly temperature (average maximum and minimum daily) values for the end century (2070-2099) along with baseline (1970-1999) (triangles). The box-whisker plot (median, 25th and 50th percentiles and minimum and maximum) are given for PRECIS (A2&B2) and REMO (A1B). (a), (b) and (c) show monthly 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.

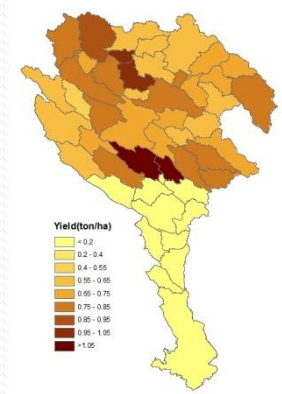
Crop (Wheat) Yield

Rain-fed

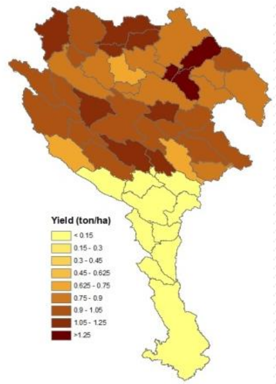
1) Baseline



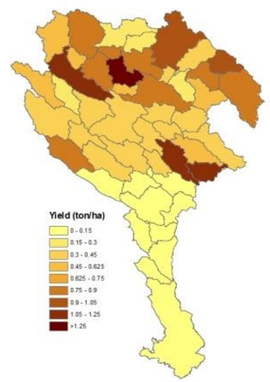
2) A1B



3) A2

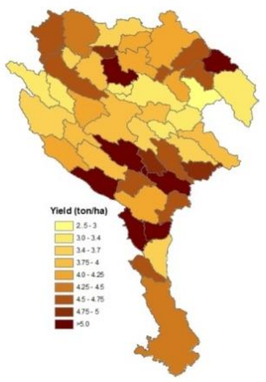


4) B2

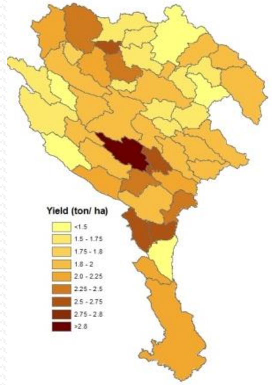


Irrigated

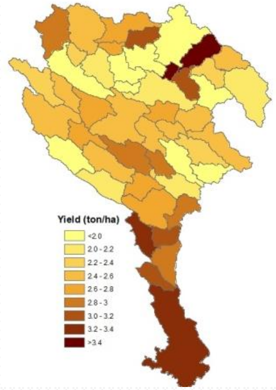
5) Baseline



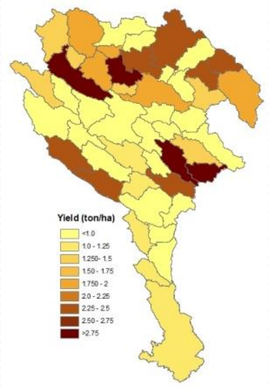
6) A1B



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.

Performances of BMPs

- 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

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

*NCC-No Considerable Change in compare to" No application"

** GSS-Graded Stabilization Structure

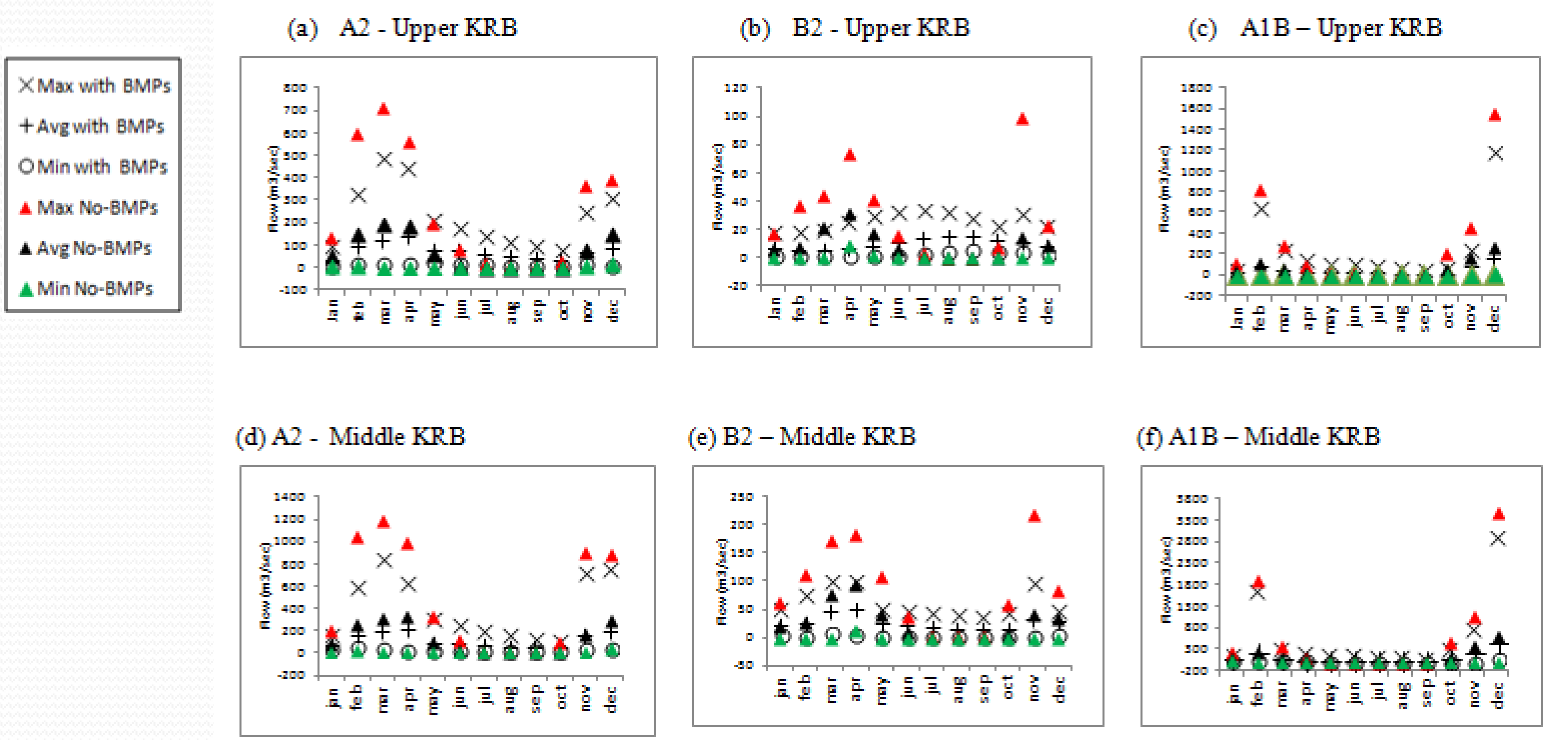
Evaluation on future climate condition (2070-2099)

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

Basin	BMPs	Statistic Results	Baseline condition	Climate Scenarios		
				A2	B2	A1B
Upper KRB	No application	Mean	46.65	76.65	10.26	58.04
		Max	718	709.2	33.45	1548
		Min	0	0	0	0
	With application	Mean	50.63	76.44	9.44	55.20
		Max	323.1	490.7	99.29	1189
		Min	6.16	8.19	1.23	1.78
Middle KRB	No application	Mean	146.28	127.61	29.38	121.48
		Max	1647	1174	217.1	3476
		Min	0	0	0	0
	With application	Mean	147.67	123.19	28.34	110.81
		Max	915.20	849.6	100.4	2882
		Min	10.11	14.4	3.128	0

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 import 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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