Estimation of Actual Evapotranspiration at Regional–Annual scale using SWAT

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Overview

- Introduction
- Material and Methods
  - Study Area
  - Data
  - Model Structure
- Results and Discussion
- Conclusion

Introduction

- Much research and many studies require a knowledge of ET.
- The main methods (e.g. lysimeter, Bowen ratio, …) have been conventionally used to measure ET at field or landscape scales; **but** regional ET cannot be measured directly.

Introduction

- Estimating ET at regional scale
  - Physical and empirical remote sensing-based models in combination with satellite data
    - Need to precise validation of estimated ET
  - Using a hydrological models
    - Fundamental elements of hydrological processes, such as precipitation, runoff, can be measured directly and imported to the model

Introduction

- Soil and Water Assessment Tool (SWAT)
  - SWAT-based ET could be used as the standard for accuracy assessment of remote sensing-based models (Gao and Long, 2008).
  - Multi-criteria calibration is required to improve model reliability.
    - Calibration using crop yield and streamflow gives more confidence on the partitioning of water between soil storage, actual evapotranspiration, aquifer recharge.

Introduction

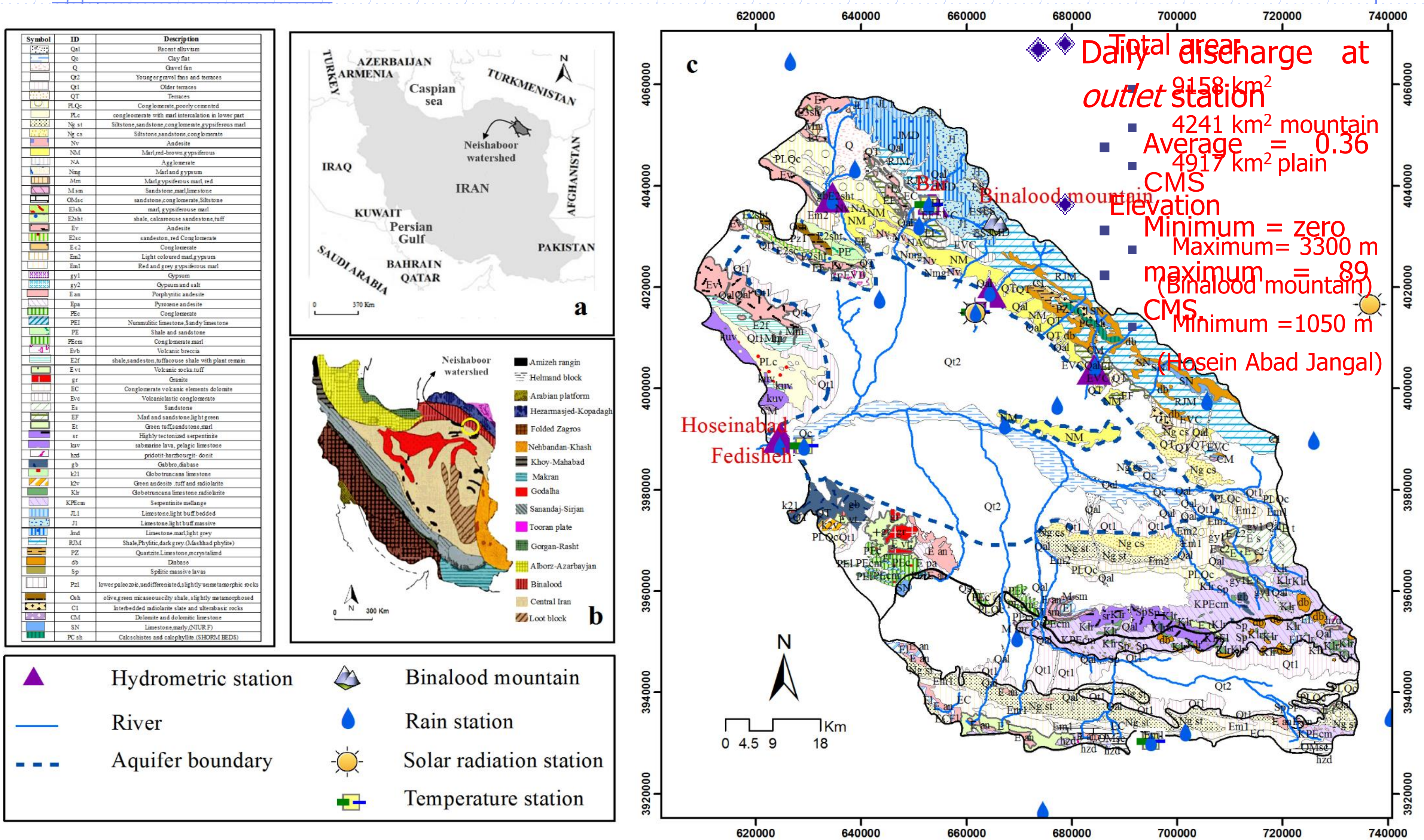
- The main objective of this study
  - Estimate **actual ET (AET)** using multi-criteria calibrated SWAT model in the Neishaboor watershed, Iran.

Study Area: **Neishaboor watershed**

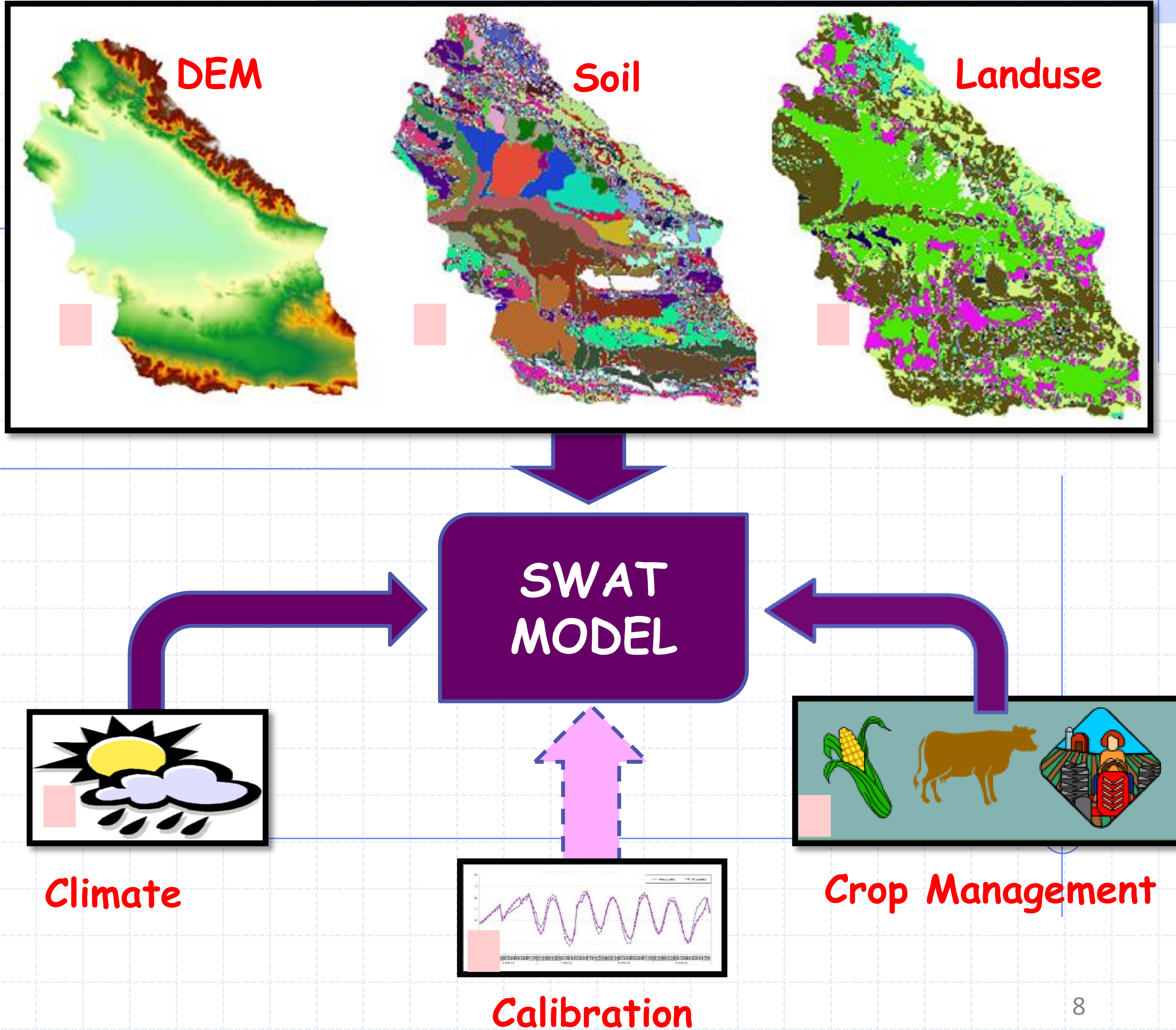
- Mean annual precipitation
  - 265 mm
- Mean annual temperatures
  - 13° C

- Total area: 9158 km²
  - 4241 km² mountain
  - 4917 km² plain
- Elevation
  - Maximum= 3300 m (Binalood mountain)
  - Minimum =1050 m (Hosein Abad Jangal)

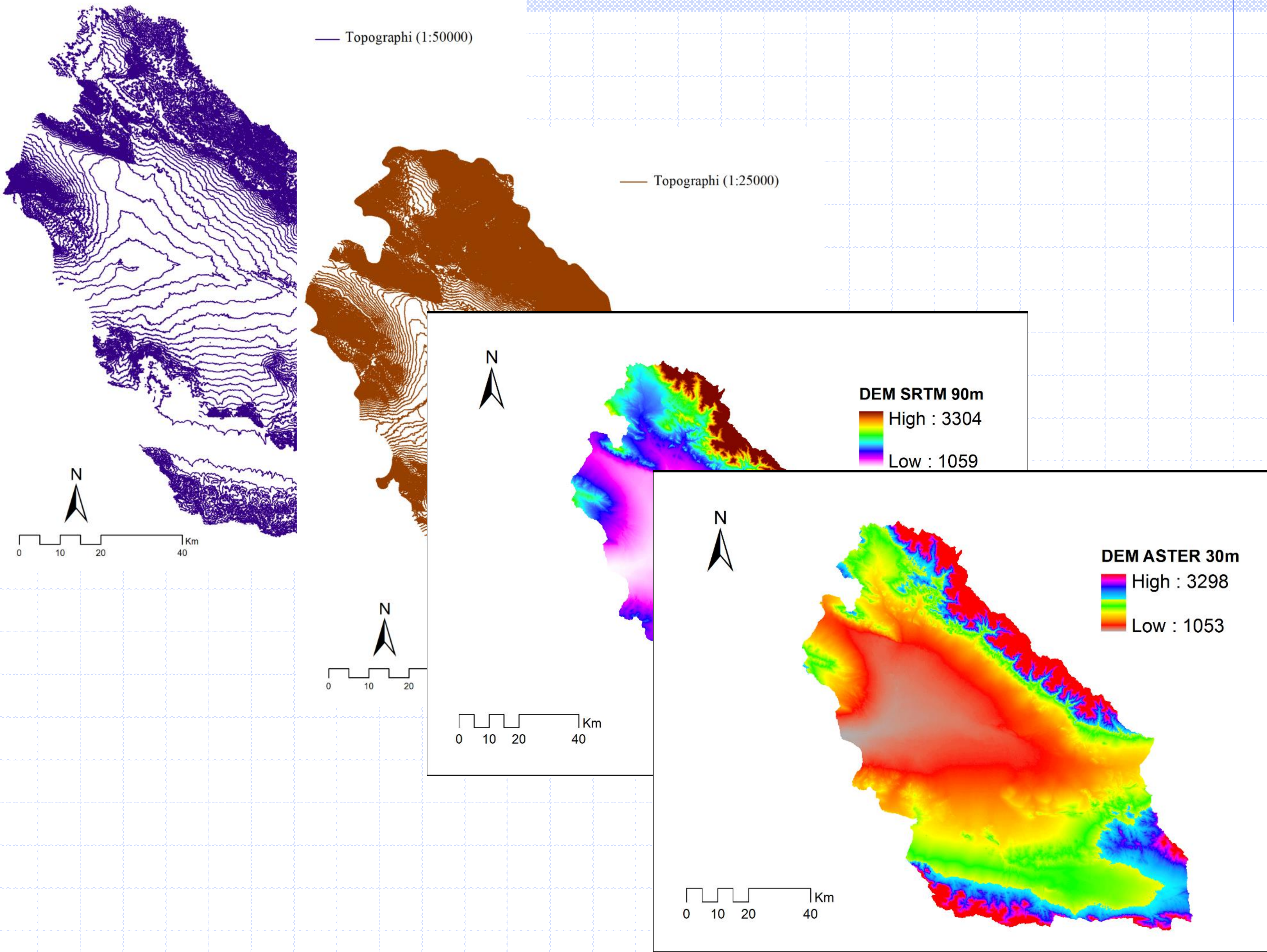
- Daily discharge at *outlet* station
  - Average = 0.36 CMS
  - Minimum = zero
  - maximum = 89 CMS.



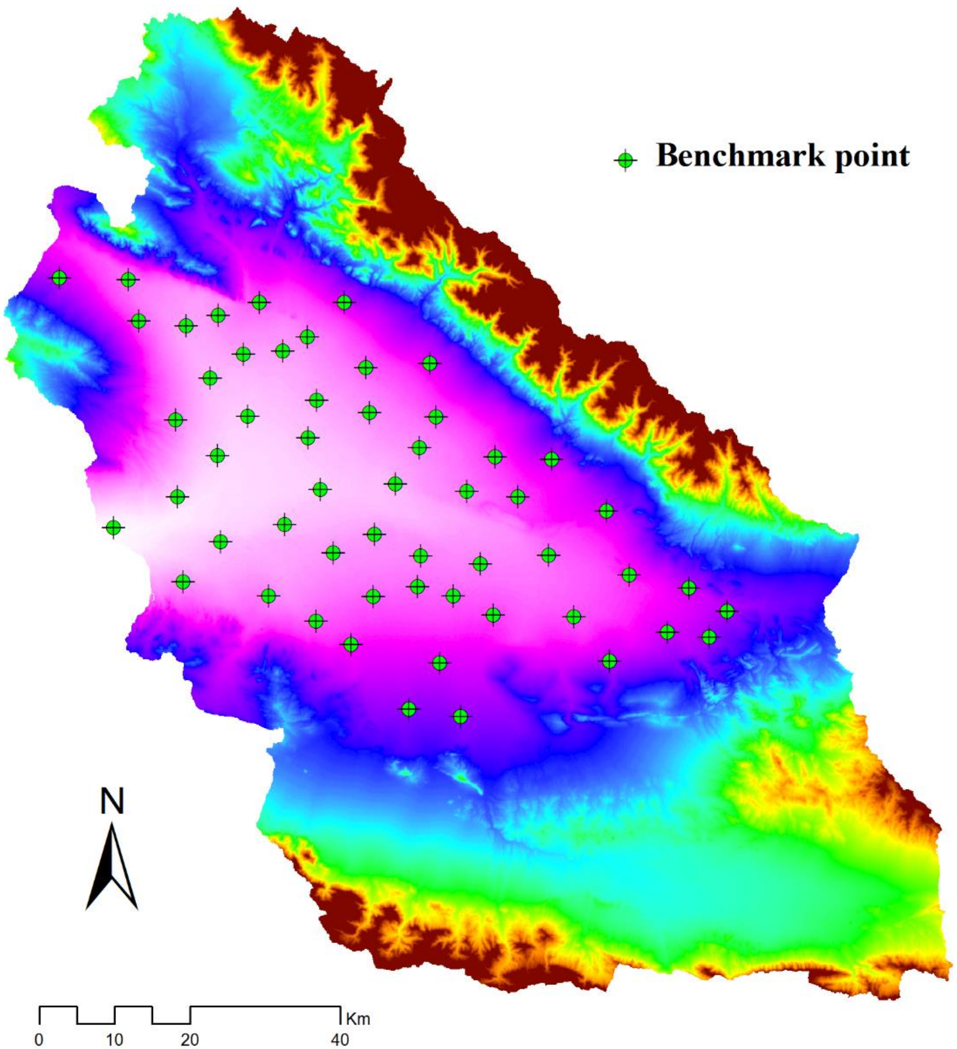
INPUT DATA



DEM
Soil
Landuse
SWAT
MODEL
Climate
Calibration
Crop Management

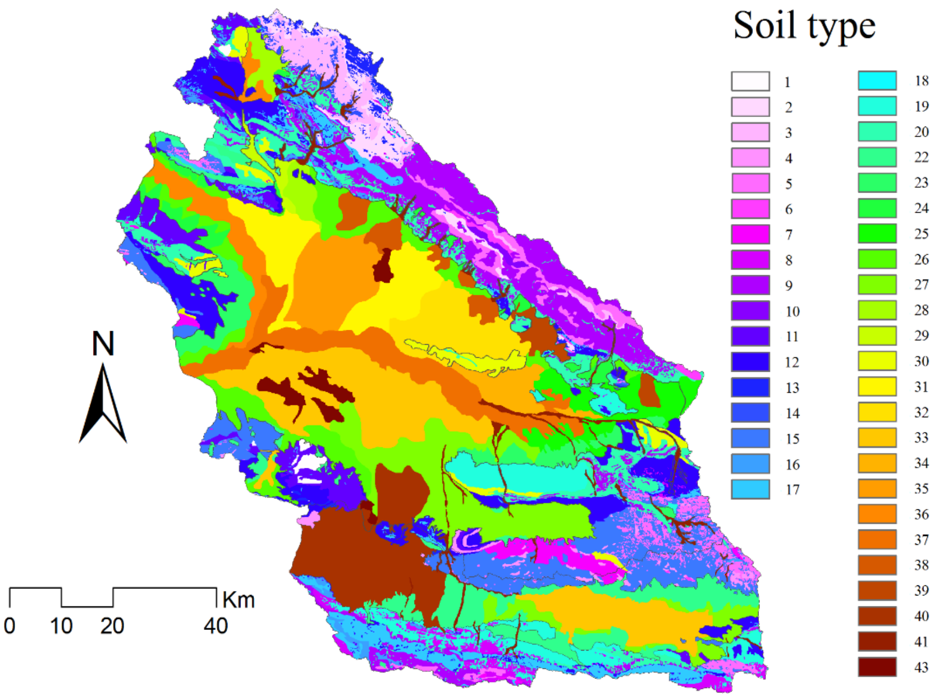


Topographi (1:50000)
N
0 10 20 40 Km
Topographi (1:25000)
N
0 10 20
DEM SRTM 90m
High : 3304
Low : 1059
N
0 10 20 40 Km
DEM ASTER 30m
High : 3298
Low : 1053
N
0 10 20 40 Km



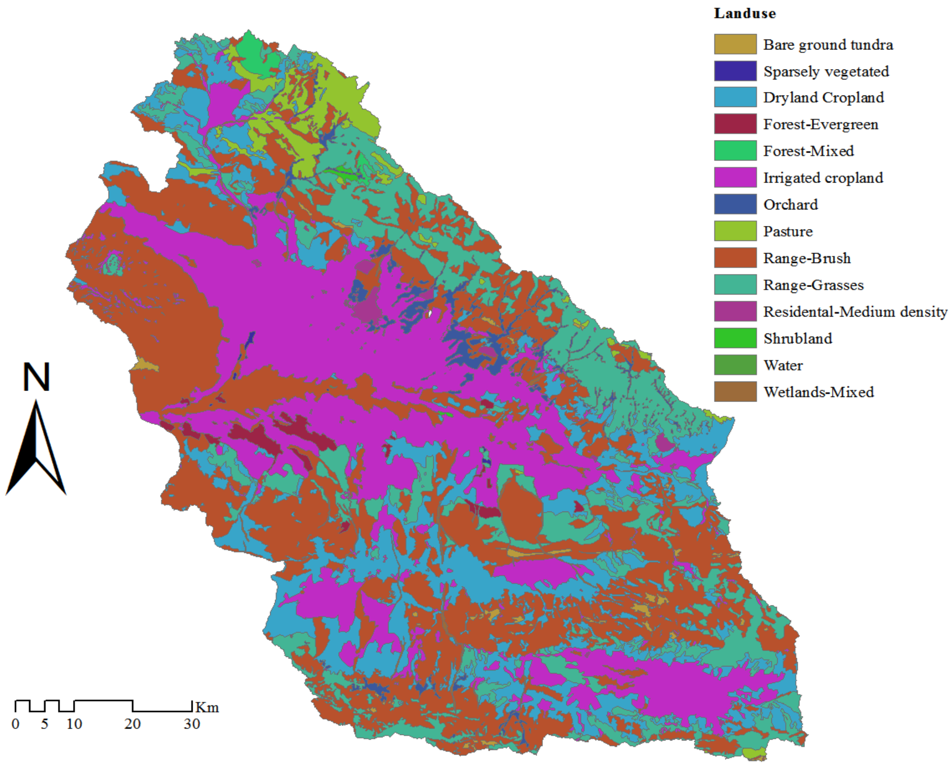
These were cross checked against each other (benchmark points), and for conflicting points a field measurement with deferential GPS technique was performed.

SRTM DEM (grid cell: 90 × 90) was selected as the base elevation model.



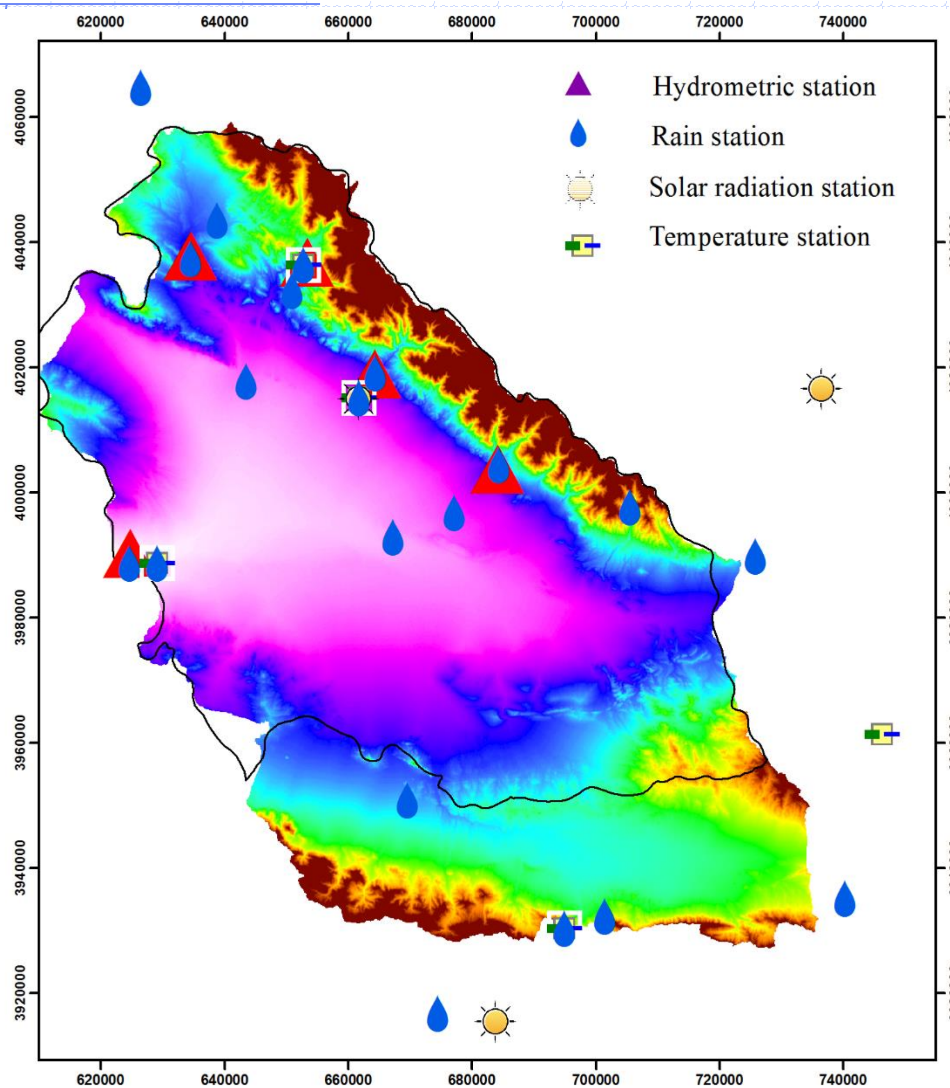
- Scale: 1:100000
- 43 types of soils

- Official reports:
  - Soil texture, rock fragment content, soil saturated hydraulic conductivity and organic carbon content
- RetC software (van Genuchten et al., 1991)
  - Other required parameters



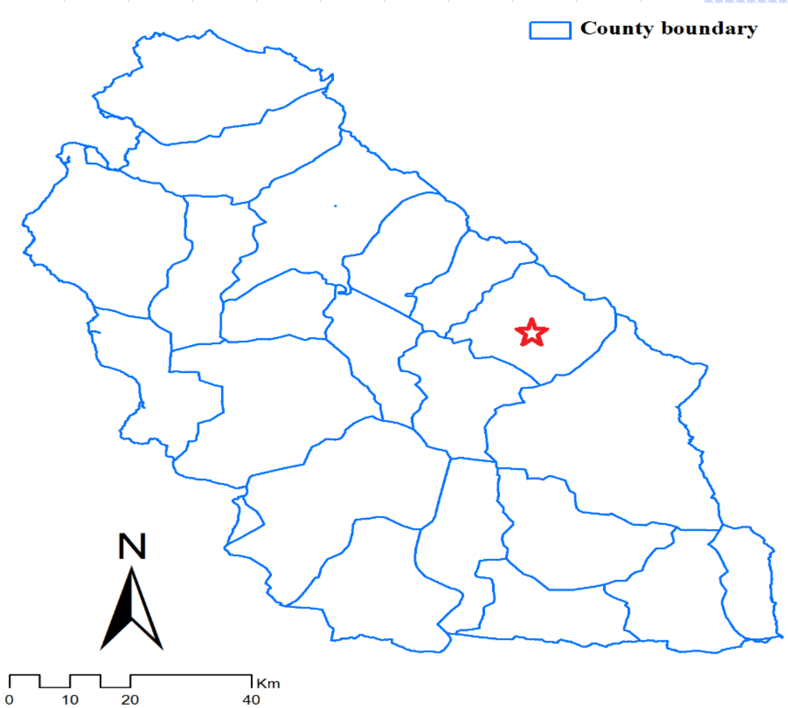
- Scale: 1:100000
- 14 main classes

- Neishaboor watershed is predominantly agricultural (47% of watershed).
  - Irrigated wheat and barley (70% of the 47%)
  - Sugar beet, cotton, and alfalfa (30% of the 47%)



- 23 rain station
- 4 temperature station
- 3 solar radiation station
- Relative humidity and wind speed
  - Weather generator

- Neishaboor watershed is an agriculture-based watershed.
- The processes affecting the water balance in an agricultural watershed are highly influenced by crop management.
- **Irrigated** and **rainfed** **wheat** crops were considered.

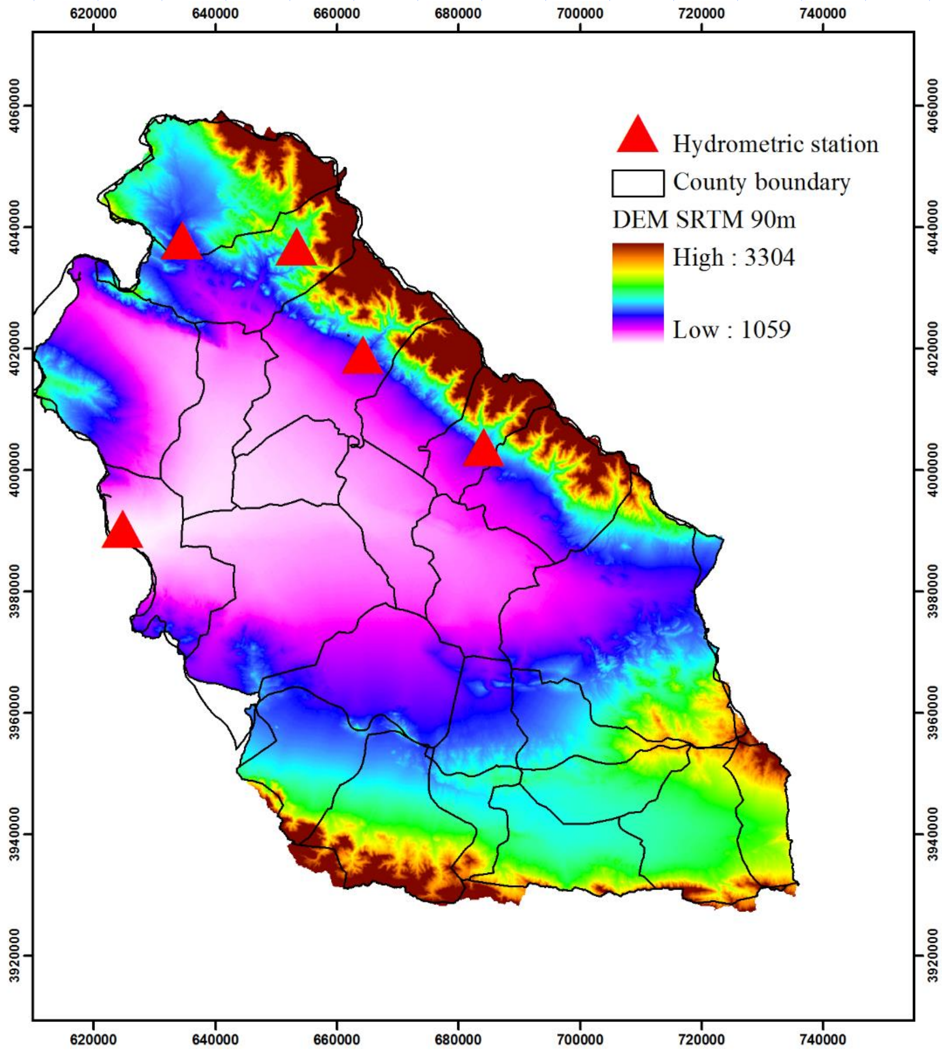


- Collecting crop management data
  - Official reports
  - Interview with large owner farmer
  - Local experts
- 21 counties separately!

	Year	Operation type	Date	Descriptions
Irrigate wheat	1	Tillage	September 26	Moldboard Plow
	1	Tillage	September 27	Leveler
	1	Planting	October 4	-
	1	Fertilizer	October 5	Phosphate (18-46-00), 150 kg/ha
	1	Auto-Irrigation	October 6	-
	2	Fertilizer	March 15	Urea, 50 kg/ha
	2	Fertilizer	April 9	Urea, 50 kg/ha
	2	Fertilizer	April 30	Urea, 50 kg/ha
	2	Harvest & Killing	July 13	-

	Year	Operation type	Date	Descriptions
Rainfed wheat	1	Tillage	November 23	Moldboard Plow
	1	Tillage	November 24	Leveler
	1	Planting	December 6	-
	1	Fertilizer	December 7	Phosphate (18-46-00), 50 kg/ha
	1	Fertilizer	December 7	Urea, 50 kg/ha
	2	Harvest & Killing	July 17	-

Hydrometric and Crop Yield Data (Calibration)



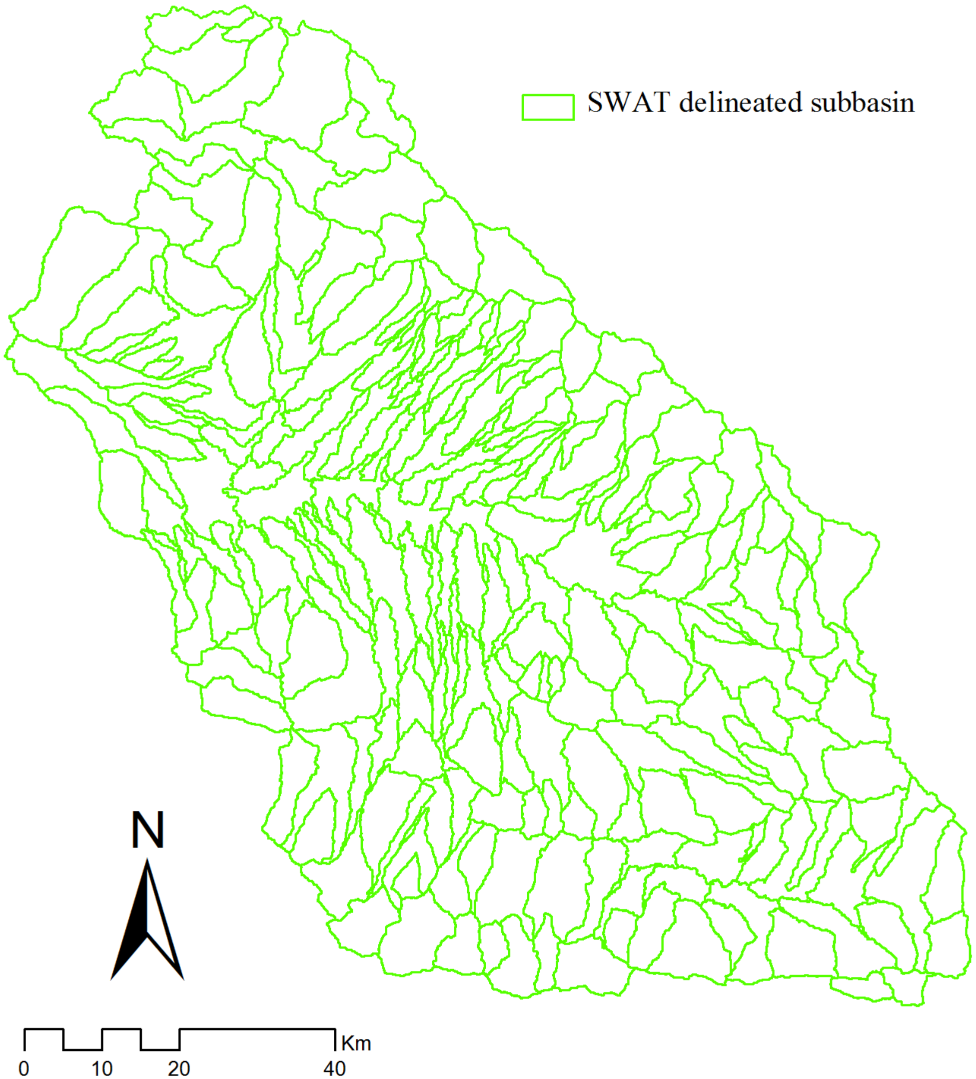
- 5 hydrometric station
- Crop yield data
  - County level
    - Irrigated wheat
    - Rainfed wheat

Model Structure:

- The simulation period: 1997–2010;
  - The first 3 years were used as warm-up period.
- Precipitation lapse rate:160 mm/km
- Temperature lapse rate: 6 ºC/km
- Five elevation bands
- Solar radiation
  - Angstrom-Prescott equation
- Calculating ETp
  - The Hargreaves method.
- Automatic irrigation
  - Difficult to know when and how much the farmers apply irrigation

Model Structure:

- Neishaboor watershed was subdivided into 248 subbasins.
  - Delineate with smallest possible threshold area (0.008%)
  - Remove all generated outlets
  - Assign new outlets regard to:
    - Mountain-plain boundary
    - Horticultural and agricultural farms border (landuse map)
    - County boundaries
    - Hydrometric station location
    - Subbasins area should be less than 1% of the watershed area



- One HRU for each subbasin was considered because of facility in entering crop management data to each subbasin
- Calibration
  - 7-year (2000-2007)
  - SUFI-2
- Validation
  - 3-year (2008-2010)

Result & Discussion

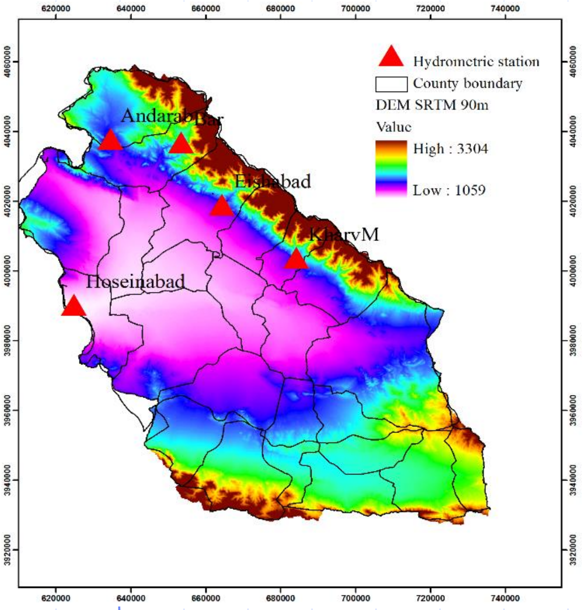
Sensitivity analysis

- 21 global parameters of hydrology were sensitive to river discharge
- All crop parameters also were sensitive to crop yield

Table 3 SWAT parameters adjusted during calibration and their sensitivity statistics and initial and final values

Parameter[a]	Physical Meaning	t-value[b]	p-value[b]	Initial range	Final range
v__TRNSRCH.bsn	Reach transmission loss	19.92	0.00	[0, 1]	[0.32, 0.57]
r__CN2.mgt	Initial SCS CN II value	18.31	0.00	[-0.5, 0.5]	[-0.42, 0.21]
v__CH_K2.rte	Effective hydraulic conductivity of channel (mm/hr)	8.24	0.00	[0, 150]	[35, 47]
v__ALPHA_BF.gw	Baseflow recession constant	3.02	0.00	[0, 1]	[0.3, 0.39]
v__CH_N2.rte	Manning's n value for the main channel	1.63	0.10	[0, 0.3]	[0.19, 0.22]
v__GW_REVAP.gw	"Revap" coefficient	1.50	0.13	[0.02, 0.2]	[0.03, 0.04]
v__SMFMN.bsn	Melt factor for snow on December 21 (mm /°C/day)	1.21	0.23	[0, 10]	[0.21, 2.47]
v__SMTMP.bsn	Snow melt base temperature (°C)	1.16	0.25	[-5, 5]	[-4.21, -2.16]
v__EPCO.hru	Plant uptake compensation factor	0.93	0.35	[0.01, 1]	[0.75, 0.81]
r__SOL_K().sol	Soil hydraulic conductivity (mm/hr)	0.90	0.37	[-0.5, 0.5]	[-0.06, 0.06]
v__SLSUBBSN.hru	Average slope length (m)	0.57	0.39	[10, 150]	[34, 43]
v__GW_DELAY.gw	Delay time for aquifer recharge (days)	0.54	0.42	[0, 500]	[471, 484]
v__RCHRG_DP.gw	Aquifer percolation coefficient	0.54	0.44	[0, 1]	[0.3, 0.47]
v__SMFMX.bsn	Melt factor for snow on June 21 (mm /°C/day)	0.45	0.65	[0, 10]	[4.87, 9.48]
r__SOL_BD().sol	Bulk Density Moist [g/cm-3]	0.42	0.67	[-0.5, 0.5]	[-0.41, -0.33]
v__SFTMP.bsn	Snowfall temperature (°C)	0.39	0.70	[-5, 5]	[0.27, 3.42]
v__ESCO.hru	Soil evaporation compensation factor	0.35	0.73	[0.01, 1]	[0.72, 0.79]
r__SOL_AWC().sol	Available water capacity	0.20	0.84	[-0.5, 0.5]	[0.23, 0.34]
v__SURLAG.bsn	Surface runoff lag coefficient	0.18	0.85	[1, 24]	[1, 7]
v__TIMP.bsn	Snow pack temperature lag factor	0.15	0.88	[0.01, 1]	[0.06, 0.67]
v__GWQMN.gw	Threshold water level in shallow aquifer for baseflow (mm)	0.14	0.89	[0, 5000]	[2388, 2812]
v__HEAT_UNITS.mgt (Irrigated wheat)	Potential heat units for plant to reach maturity	-	-	[500, 5000]	[3798, 4121]
v__HI_TARG.mgt (Irrigated wheat)	Harvest index target	-	-	[0, 1]	[0.52, 0.63]
v__AUTO_WSTRS.mgt (Irrigated wheat)	Water stress that triggers irrigation	-	-	[0, 1]	[0.86, 0.90]
v__HEAT_UNITS.mgt (Rainfed wheat)	-	-	-	[500, 5000]	[2341, 2735]
v__HI_TARG.mgt (Rainfed wheat)	-	-	-	[0, 1]	[0.13, 0.26]

- Due to high stream bed water losses in semi-arid and arid streams, most of the infiltration is through stream bed.
- Runoff is controlled by the reach transmission loss (TRNSRCH) in these regions (Sorman and Abdulrazzak, 1993; Scanlon et al., 2002; de Vries and Simmers, 2002; Sophocleous, 2005; Scanlon et al., 2006; Wheater, 2010; Edmunds, 2010; Yin et al., 2011)



- Hydrology calibration and uncertainty analysis
  - The calibration process was initiated from the upstream gauges - ***Andarab***, ***Bar***, ***Eishabad*** and ***Kharvm*** - as well as ***Hoseinabad***.

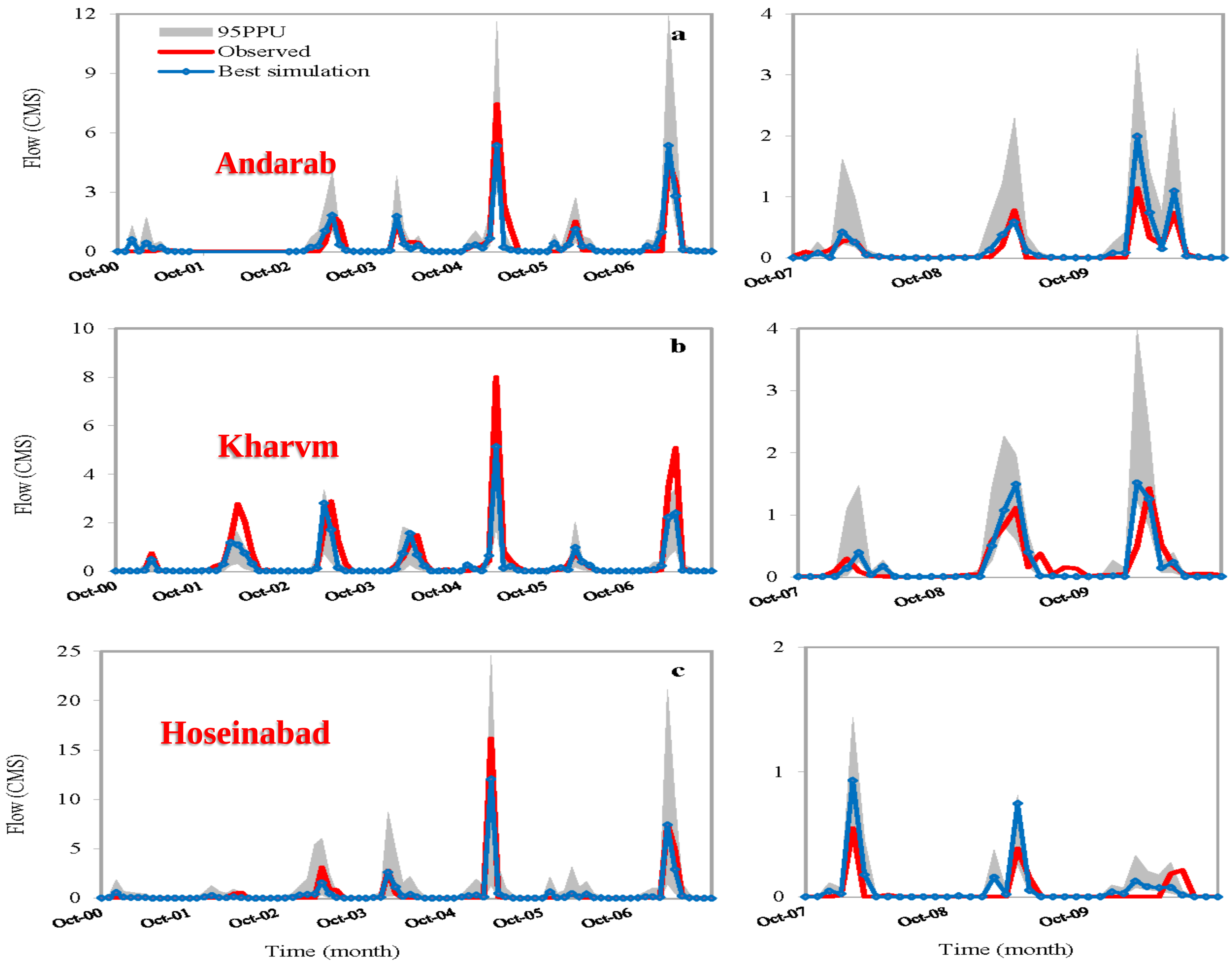
- SWAT could not predict the base flow except for ***Andarab*** station. Because, in these stations the base flow of the river is mainly comes from springs.
- The springs were imported in these subbasins as point sources. But, the P-factor value increased only in the ***Kharvm*** station.

- Inappropriate results in the ***Bar*** and ***Eishabad*** hydrometric stations:
  - Severe elevation variability of these subbasins.
  - Unaccounted human activities affecting natural hydrology during the period of study.
  - Snow parameters are not spatially defined.
  - Shortcomings of the SCS method
    - It cannot simulate runoff from melting snow and on frozen ground
    - It does not consider the duration and intensity of precipitation

Eishabas and *Bar* station was removed from calibration period.

- After calibrating *Andarab*, *Eishabad* and *Hoseinabad* separately, entire watershed was calibrated by considering fixed hydrology parameters for these stations.

Hydrometric station	P-factor	R-factor	R2	NS	RMSE (CMS)
Andarab	0.42 (0.36)[a]	0.35 (0.41)	0.85 (0.79)	0.84 (0.79)	0.212 (0.005)
Kharvm	0.45 (0.42)	0.37 (0.61)	0.87 (0.74)	0.77 (0.66)	0.326 (0.036)
Hoseinabad (watershed outlet)	0.37 (0.42)	0.68 (0.63)	0.82 (0.71)	0.79 (0.71)	0.321 (0.004)



95PPU
Observed
Best simulation
a
Andarab
b
Kharvm
c
Hoseinabad
Flow (CMS)
Time (month)
Oct-00
Oct-01
Oct-02
Oct-03
Oct-04
Oct-05
Oct-06
Oct-07
Oct-08
Oct-09

Crop yield calibration and uncertainty analysis

- Calibration of a large-scale distributed hydrologic model – 9159 km2 - against streamflow alone may not provide sufficient confidence for all components of the surface water balance.
- Crop yield is considered as an additional target variable in the calibration process.

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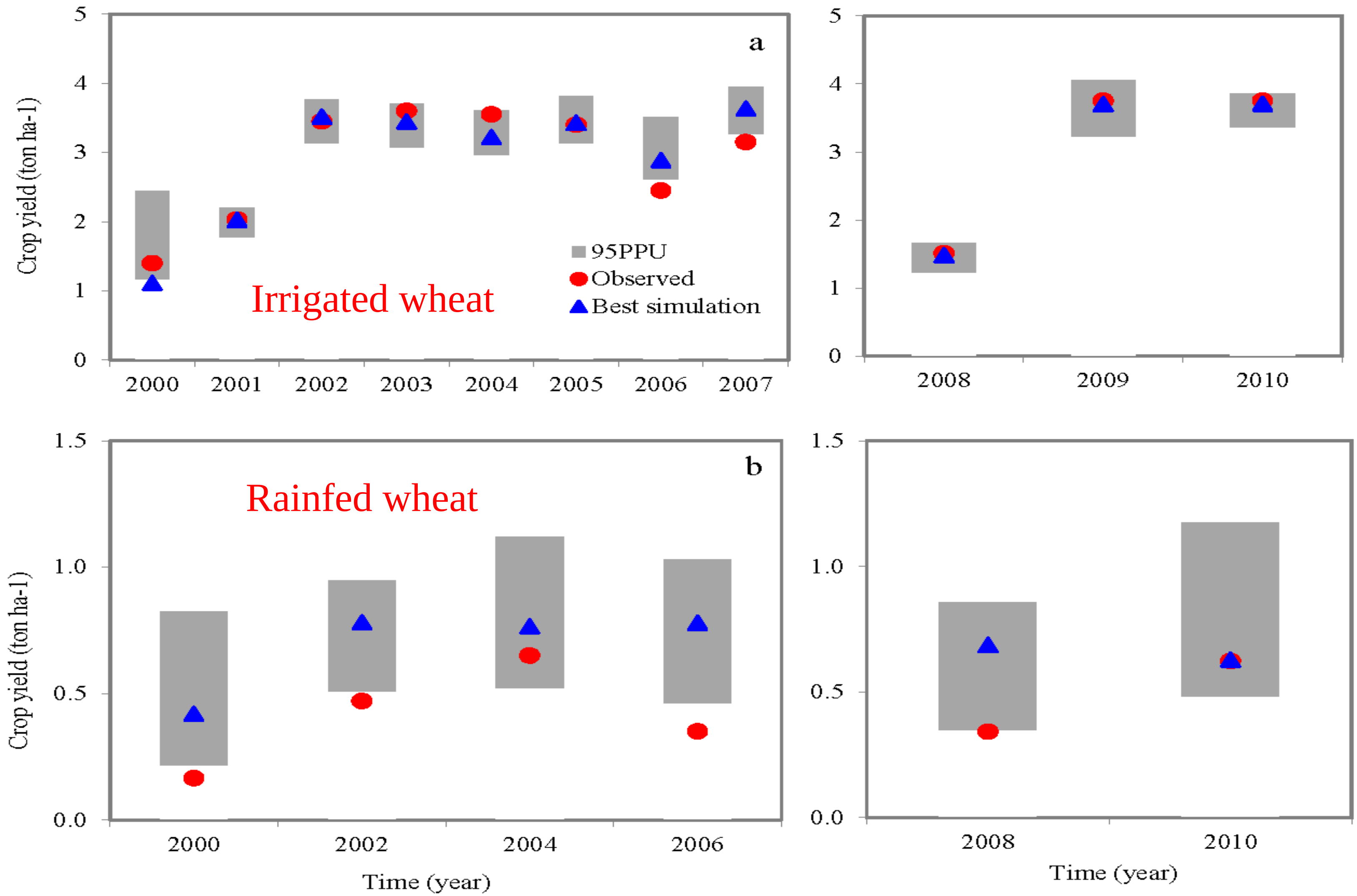
v__HI_TARG.mgt (Rainfed wheat)	-	-	-	[0, 1]	[0.13, 0.26]

Crop yield calibration and uncertainty analysis:

Crop	R-factor	RMSE (ton ha^{-1})
Irrigated wheat	0.97 (0.57)[a]	0.080 (0.012)
Rainfed wheat	1.16 (1.21)	0.045 (0.039)

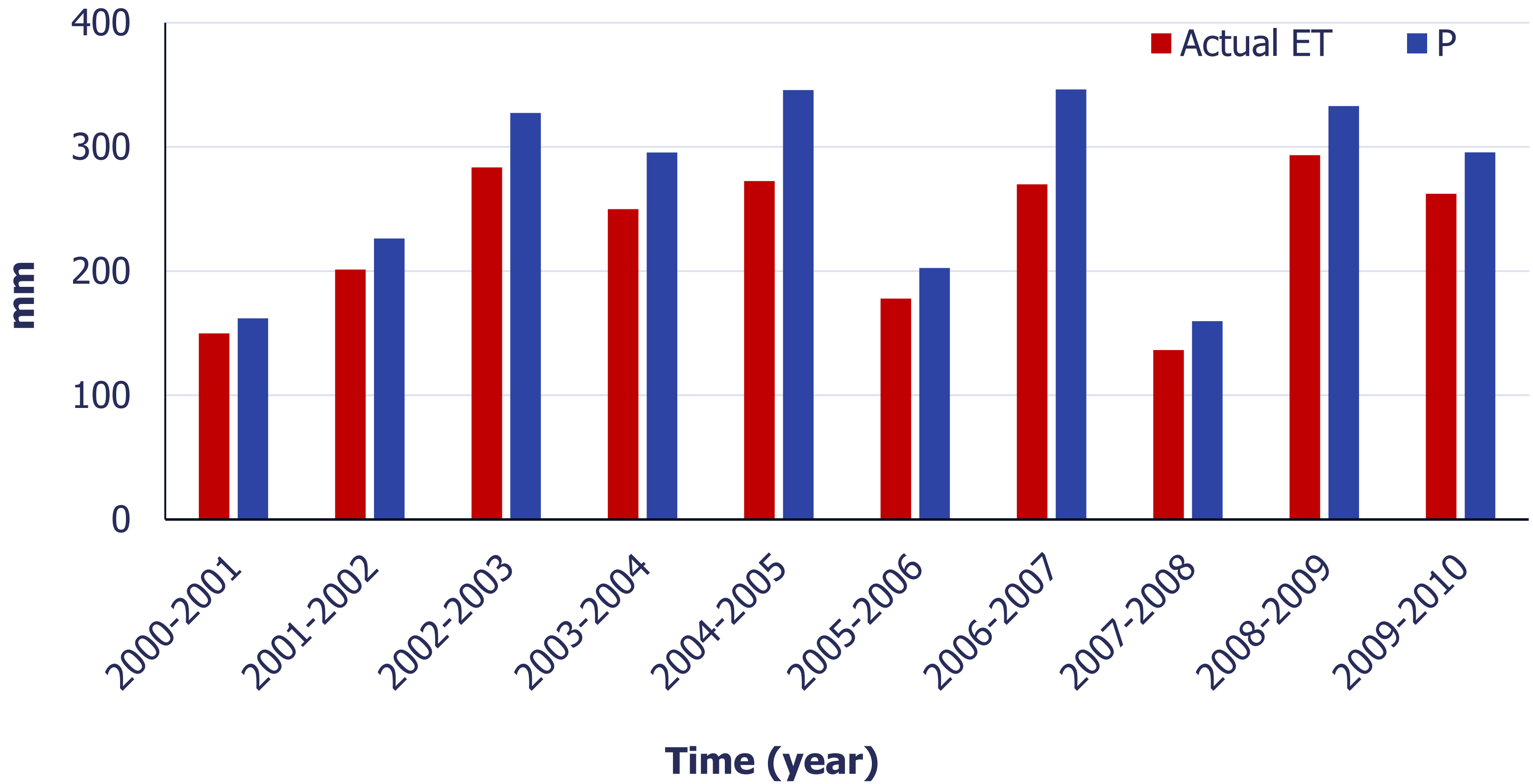
- SWAT was able to predict crop yield satisfactorily for irrigated wheat.
  - Collecting crop management information at farm scale precisely (21 counties)

Plots of observed and simulated annual crop yield



Estimation and analysis of actual evapotranspiration

- The results showed that SWAT provided satisfactory predictions on **hydrologic budget** and **crop yield**. Hence, the multi-criteria calibrated model was then used to estimate and analyze the actual evapotranspiration at regional-annual scale.



Mean annual precipitation and actual ET

Estimation and analysis of actual evapotranspiration

- $\bar{P}$= 270 mm
- $\overline{ET}_a$= 230 mm
- $\overline{ET_a}/P \times 100$ in mountainous:

  Dry year (2000-2001): 99%

  Normal year (2001-2002): 80%

  Wet year (2004-2005): 77%

$\rightarrow \overline{ET_a}/P \times 100 = \%85$ **Whole watershed**

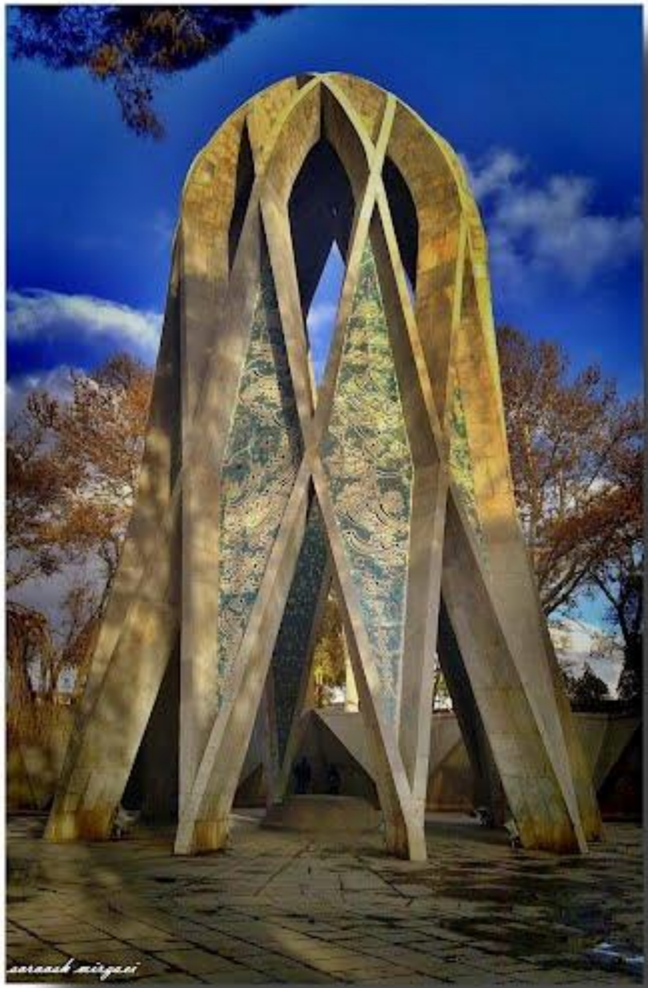
This ratio shows only the actual evapotranspiration from precipitation to precipitation ratio.

Estimation and analysis of actual evapotranspiration

- Groundwater is another source of water supply for irrigation purpose in the plain as well as precipitation. This source effects the actual ET considerably. Therefore, this ratio shows the total actual evapotranspiration (**precipitation** and **irrigation**) to precipitation ratio.
- Estimation of this ratio is not as simple as mountainous part of watershed due to uncertainties in the crop pattern data and their water requirements.

Conclusion

- SWAT provided satisfactory predictions on hydrologic budget and crop yield.
- This study could be used to evaluate the estimated actual ET using RS.
- To enhance the performance of the model, crop management parameters of other major crops such as sugar-beat, cotton and alfalfa is necessary.

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