Journal of Hydrology 585 (2020) 124762

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Basin-wide water accounting based on modified SWAT model and WA+ framework for better policy making

M. Delavar[a,*], S. Morid[a], R. Morid[b], A. Farokhnia[a], F. Babaeian[a], R. Srinivasan[c], P. Karimi[d]

[a] *Department of Water Resources Engineering, Tarbiat Modares University, Tehran, Iran*
[b] *Kyushu University, Fukuoka, Japan*
[c] *Department of Ecosystem Science and Management and Department of Biological and Agricultural Engineering, Texas A&M University, USA*
[d] *IHE Delft Institute for Water Education, the Netherlands*

ARTICLE INFO

This manuscript was handled by Syme, Editor-in-Chief

Keywords:
Water resources systems
SWAT model
Water Accounting Plus (WA$^+$)
Water saving
Evapotranspiration management

ABSTRACT

Evaluation of water resources systems and implementation of appropriate management strategies requires accurate and well classified information describing supply, demand, and consumption. The WA+ water accounting framework is a relevant tool in this regard. Earlier applications of the WA+ framework draw heavily from remote sensing (RS) data; however, applying RS data limits the application of the framework to past and current situations. Such analyses are needed for future assessments due to new management and climate scenarios. Therefore, the objective of this research is to link WA+ with the Soil Water Assessment Tool (SWAT) model to enhance it and to evaluate water management strategies through an integrated framework. The resulting system, SWAT-FARS (customized version of SWAT model for Fars region) is capable of supporting macro and micro water planning through a systematic presentation of the past trends, current and future status in water supply and demand. To explore this methodology, the system was applied to the Tashk-Bakhtegan basin (Iran). The trends in supply and consumption within the basin and some of the water saving policies that are mandated by the country's 6th development plan were evaluated. Application of SWAT-FARS to the Task-Bakhtegan basin showed decrease in "Manageable water" of about 23% and a simultaneous increase of "Incremental irrigation" of about 53%; this lack of accessible water and imbalance of manageable water and water usage has almost omitted the basin's "Outflows". To alleviate pressures on the basin's water resources, a suggested elimination of rice cultivation and improving pressurized irrigation showed the first policy could reduce water consumption by 0.08 BCM/yr and the second one can even increase water consumption by 0.25 BCM/yr over current conditions. The methodology used to develop SWAT-FARS is strongly recommended for other regions suffering water scarcity.

1. Introduction

Analyzing water resources systems and developing appropriate management strategies requires access to accurate information describing supply, demand, and consumption. With this data, a comprehensive picture can be built to help evaluate best management strategies, identify opportunities for reducing water requirements, increasing water productivity and so on.

To achieve the aforementioned mission, the International Water Management Institute (IWMI) developed the water accounting concept (Molden, 1997). Water accounting provides a means with which to summarize water use across varying spatial scales, distinguish between "withdrawal" and "consumption", and to describe water/soil productivity more precisely. FAO (2012) also describes water accounting as the systematic acquisition, analysis, and communication of information relating to stocks, flows, and fluxes of water (from sources to sinks) in natural, disturbed, or heavily engineered environments. So far, different frameworks have been introduced in this regard, like: IWMI-WA (Molden, 1997), SEEAW[1] (Perry, 2012) and GPWA[2] (Chalmers et al., 2012). The IWMI-WA framework (Molden, 1997) was later improved through joint work by IWMI, FAO, and IHE (Karimi et al., 2013a) and called "Water Accounting Plus" (WA+). WA+ shares the same fundamentals of IWMI-WA, especially on differentiating "consumption" and "withdrawal" while considering a stronger link with land use and provides more details in its main processes and mechanisms.

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* Corresponding author.
E-mail address: m.delavar@modares.ac.ir (M. Delavar).

[1] - System of Environmental-Economic Accounts for Water.
[2] -General Purpose Water Accounting.

https://doi.org/10.1016/j.jhydrol.2020.124762
Received 17 November 2019; Received in revised form 23 February 2020; Accepted 24 February 2020

To summarize the water resources situation of a desired basin; WA+ presents four sheets including (i) a resource base sheet, (ii) an evapotranspiration sheet, (iii) a productivity sheet, and (iv) a withdrawal sheet. The required data for each sheet can be obtained through remote sensing (RS) based data; a feature that makes it very relevant and practical for data scarce areas and for large scale applications as it was applied for the Indus Basin (1,160,000 km^2) and the Helmand Basin (262,342 km^2) (Karimi et al., 2013b). However, applying RS data limits the application of the WA+ framework only to past and current situations and may not be relevant for small subbasins due to existing uncertainties that would be amplified as the spatial scale of application grows finer. These limitations could pose a legitimate obstacle for the application of WA+ beyond regional studies (Karimi and Bastiaanssen, 2014).

A possible solution to the aforementioned problem is to build on the fact that input data for WA+ can also be obtained from hydrological simulation and water allocation models (Karimi et al., 2013a). In this manner, it would be possible to capitalize on various hydrological simulation models such as HSPF, VIC, Mike Basin, WEAP, and the Soil Water Assessment Tool (SWAT).

As evident from different literature (e.g. Tibebe and Bewket, 2011; Ramos and Martínez-Casasnovas, 2015; Krysanova and Srinivasan, 2015; Jha et al., 2015) SWAT (Arnold et al., 1998) is widely used to simulate hydrological condition in a changing environment as well as to simulate and assess best management practices. This function of SWAT is an important added value when the model is used as an integral part of WA+ and makes it possible to look into water accounts under different climate and management scenarios. The climate scenarios can be future climate change projections (Rezaei Zaman et al., 2016; Harrison et al., 2019) or even past scenarios showing possible trends in rainfall and temperature (Rodgers et al., 2019). These options are possible because of SWAT's capabilities of rainfall-runoff simulation and calculation of water balance components at the farm (through hydrological response units (HRUs)) and basin scales. For more description; SWAT is semi-distributed, dividing each subbasin into smaller HRUs (Neitsch et al., 2002) based on soil type, crop patterns, and management practices. To do this, the model includes many modules, including crop growth, groundwater, and river routing to accommodate the required simulations. Another advantage of including these scales relates to possibility of the 'rebound effect' evaluation. In reality, measures at farm scale do not necessarily lead to reduce water consumption at basin scale. It can be due to decrease in return flows and deficit irrigation or even increase of evapotranspiration because of better water application (Gonzalez, 2019). Raeisi et al. (2019) also evaluated the 'rebound effect' of improving drip irrigation using SWAT model. Furthermore, using many different types of observed ground data (e.g. long term hydro-climate records, land use, soil data, etc.) by the model, makes it to be associated with less uncertainties comparing with RS-based water accounting framework. Of course, uncertainty analyses of the framework can be done using the relevant tools (e.g. SWAT-CUP (Abbaspour, 2015).

In order to link SWAT and WA+, there are some compatibility issues that had to be addressed first. The main one is matching the official geographical units of the water resources departments with how SWAT delineates basins. For instance, the hierarchy of hydrologic units of the USA include 4 levels: Regions, Subregions, Accounting Units and Cataloging Units (Seaber et al., 1987). In case of the study area for this research (Iran), hydrologic units also fall into 4 levels, including rank 1 to rank 3 basins and a lower unit, "Study Regions (SR)". So, the SR (or Cataloging Unit) is the minimum geographical unit (with total area varying from 2420 to 572290 ha) that is needed to evaluate water resources.

To meet the data requirements for WA+ at the SR resolution; SWAT faces a few limitations, especially from the groundwater simulation point of view. Giving more clarifications, it is possible that the natural hydrologic boundaries of a stream and of the groundwater flow parts of a system do not coincide (Johnson et al., 2010). In such a situation, the original form of groundwater simulation in SWAT would not be applicable since SWAT simulates spatial variations of groundwater volume and depth for each subbasin's HRUs without considering their interactions with adjacent subbasins (Kim et al., 2008). Moreover, agricultural water saving practices (e.g. improving irrigation efficiency) are the most popular practices to reduce pressure on water resources; however, there are some reports about weakness of simulation of this option in SWAT (Dechmi et al., 2012), mainly due to its limitations in simulation of water losses during irrigation events. So, the application of the SWAT model for analyzing such management practices requires some modifications. In addition, there are limitations in the original version of the SWAT model in regard to simulating specific conditions of basins (e.g. Groundwater interaction) and reporting some of the required WA+ variables (e.g. Transpiration).

The aim of this paper is to enhance capabilities of the WA+ framework through linkage to the SWAT conceptual model. The most important considered features to design this framework includes: (1) assessment of climate and non-climate scenarios (i.e. management strategies) through a water accounting framework, (2) to be suitable for any geographic scale (e.g. entire basin, subbasins and cataloging units (per the specific need of our case study)), (3) including both micro and macro planning.

To achieve these objectives, it would be investigated how limitations of the SWAT can be rectified and how the required data for the WA+ sheets can be retrieve from different modules of the model.

To explore the methodology and suggested system, Task-Bakhtegan basin is selected as the case study.

2. Material and methods

2.1. Study area and data

The Tashk-Bakhtegan basin is located at longitude 51° 42′ to 54° 33′ E and latitude 29° 2′ to 31° 15′ N (Fig. 1) with a total area of approximately 27,520 km2. The basin includes 4 subbasins and 22 SRs outlined by the Fars Regional Water Authority. The Tashk and Bakhtegan lakes are the destination of all rivers in the basin and serve as important natural habitats, especially for migrating birds. The climate of the region is a semiarid karst basin with annual average rainfall of 320 mm and annual average pan evaporation varying from 1763.1 to 2849.4 mm (MOE, 2017).

The basin is composed of large agricultural areas with intensive irrigation; more than 60% of the irrigated area is dependent on groundwater resources. This basin has historically provided resources for significant social, economic and ecologic activities for centuries (the remains of Persepolis are located here, the ceremonial capital of the Achaemenid Empire, one of world's most ancient civilizations and registered in UNESCO as part of a national list of Iranian monuments). However, this region has suffered from water shortage for over 50 years. To alleviate this water scarcity, several reservoirs have been built in recent decades.

The provided data and respective sources for the case study are shown in Table 1 and includes spatial remote sensing (e.g. DEM, soil and land use), hydro-climate, agriculture management, and the hydro-structure data.

2.2. Water Accounting Plus (WA$^+$) framework and input data

As it was stated before, the WA+ framework provides four main standard reporting sheets including resources, evapotranspiration, withdrawal, and productivity (Table 2). This study only focuses on the first three sheets, resources, evapotranspiration, and withdrawal. The 'resources sheet' contains information on water volumes including inflows and outflows and how the water is consumed and its processes. The 'evapotranspiration sheet' provides information on the

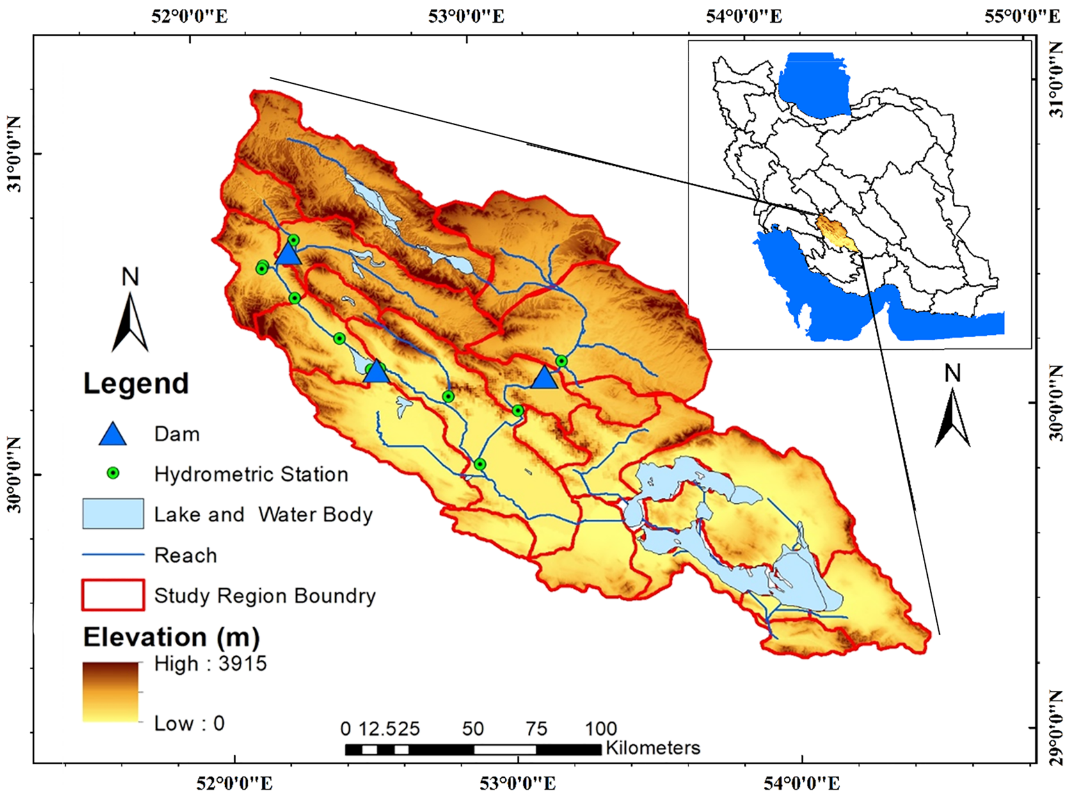


Fig. 1. Location of the Tashk-Bakhtegan basin, 22 study regions (SR) and measured discharge stations.

evapotranspiration conditions in the basin and indicates which parts of evapotranspiration processes are manageable (i.e. evapotranspiration from modified land use (rainfed) and residential, irrigated crops, reservoirs) and/or unmanageable (i.e. evapotranspiration from protected land use including shrub land, forests, glaciers, wetlands, natural grasslands). Also, it contains information on the consumed fraction of water. It means that how the part of the water applied is evaporated and transpired or consumed. The consumed water is distinguished into both beneficial and non-beneficial components. Beneficial water consumption is the amount of consumed water for transpiration of natural plants and agricultural crops, but non-beneficial water consumption indicates the water consumed that is lost from the system through interception, soil evaporation, groundwater evaporation, and evaporation from water surfaces like rivers and reservoirs and conveyance systems as well as weed transpiration (Willardson et al., 1994). The 'withdrawal sheet' provides information on how the water flows in managed water lands including the water withdrawal (i.e. the amount of water applied) from surface water and groundwater resources for irrigation, the amount of consumed water, water losses and return flows (Karimi et al., 2013a). Return flows are the non-consumed water, i.e. the difference between applied and consumed water for example surface runoff and deep percolation (Lankford, 2012). The non-consumed water includes both recoverable and non-recoverable components. All return flows are not recoverable due to degradation through nutrient leaching and salinity for example flows enters the ocean or brackish water bodies including percolation into saline aquifers, drains without downstream diversion, non-recoverable sinks physically or economically. Recoverable return flows are water flows that are reused for example return flows to a water source (drains and rivers) and percolation from irrigated lands into freshwater aquifers. Water losses are also related to non-recoverable return flows of the non-consumed water fraction as well as non-beneficial evaporation including evaporation from surface irrigation networks or conveyance systems (Perry, 2007). The consumed (beneficial and non-beneficial) and non-consumed (recoverable and non-recoverable) water terms have been adopted by Willardson et al. (1994), Allen et al. (1997), Lankford (2006), Perry (2007), Perry

Table 1
Data description and sources.

Data type	Resolution/characteristics	Source
DEM	30 m	Advanced Space borne Thermal Emission and Reflection Radiomete (ASTER GDEM2), http://gdex.cr.usgs.gov/gdex/
Soil	1 km	Harmonized world soil database, http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/en/
Land use	30 m for 1987, 2000 and 2015	Iran Water research institute
Climate	26 stations	Iranian Meteorological Organization
River discharge	11 stations	Ministry of Energy
Crop yield	Major cropping pattern	Iranian Ministry of Jahade-Agriculture (MOJA)
Agricultural management and water resources	Planting, harvesting, fertilization-blue water use	Iranian Ministry of Jahade-Agriculture (MOJA) Iran National Water Document (INWD) (Alizadeh and Kamali, 2007) Iran Comprehensive Water Management Plan
Population and water use rate	–	Iran Comprehensive Water Management Plan
Dam characteristic and operation	–	Iran water management company

Table 2
The reporting sheets of WA+ framework (adapted from Karimi et al., 2013a).

Reporting sheets	Application	Required data/information
Resource base	Assessment of the manageable, unmanageable water, over–exploitation, utilizable flows, water security, sustainability	Rainfall, ET, storage, outflow, net withdrawals
Evapotranspiration	Identifying the Beneficial and non-beneficial flows, water consumption by land use classes, manmade impact on water consumption.	Evaporation (E) from soil and water bodies, transpiration (T)
Withdrawal	providing overview of surface water and groundwater withdrawals, recoverable and non–recoverable flow and water recycling	Withdrawals, consumptive use, return flow, drainage, recharge
Productivity *	Identifying the Biomass returns, food security and water productivity.	Yield, consumptive use and water productivity

* not used in this study

et al. (2009), and Jägermeyr et al. (2015) as well as the water accounting developed by Molden (1997). Appendix A summarizes the definitions of WA+ terms. For more details refer to these studies and Appendix A.

WA+ also provides the possibility to present its results based on sets of indicators and indices. These sets help users better understand the current state of water resources, issues, future challenges, and analyze various management strategies.

2.3. SWAT model and data

SWAT is a conceptual and semi-distributed hydrological model (Arnold et al., 1998). It is capable of simulating and predicting the effects and side effects of various management conditions (e.g. watershed management, planting and harvesting management, irrigation, pesticide and fertilizer management and, crop pattern and rotation) on quantity and quality of water. The model discriminates a basin into subbasins and each subbasin is later separated into Hydrological Response Units (HRUs). These units have the same soil type, land use and slope (Arnold et al., 1998). In the model, the hydrological cycle is simulated based on the water balance equation for each HRU:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \tag{1}$$

where SW_t is the amount of soil water content at t, SW_0 is the initial amount of soil water content and R_{day}, Q_{surf}, E_a, W_{seep} and Q_{gw} are the amount of precipitation, surface runoff, actual evapotranspiration, percolation, and return flow originating from groundwater (all in mm) at the time i (day), respectively. Hydrological simulation of river basin in SWAT is performed in two stages. Phase 1, or land phase, includes simulation of the values of the main inputs such as water and sediment from each subbasin into drainage channels. Phase 2, or water routing phase, looks to the movement of Phase 1′s components in drainage networks to the outlet of the basin.

More specifically, consumption and withdrawal as the key components of WA+ are simulated in the model in a land phase simulation module. The only water consumption from agricultural regions with no flow to sinks includes ET (i.e. canopy interception, crop transpiration, and soil evaporation). Agricultural water withdrawal is also estimated by both auto-irrigation and manual irrigation subroutines. Manual management scheduling inputs in SWAT allows the users to define the actual field-scale schedule agricultural practices by specific date or heat unit accumulations (Neitsch et al., 2009).

2.4. Modifications for linkage of SWAT and WA$^+$

In order to link the SWAT and WA+ frameworks and extract the required information, it is very important to deeply understand the integration of hydrological and agricultural processes in basin simulation and how SWAT handles this task. Table 3 shows the WA$^+$ sheets and required information as well as the related variables in the SWAT outputs. The table also reveals how variables that are not originally provided can be filled in through modifications of the SWAT model. These modifications, as show in Table 3, adjust the model to (a) simulate daily groundwater level, (b) simulate interactions and exchanges of groundwater volume among different subbasins, (c) simulate the water losses during irrigation events, (d) simulate effects of dynamic changes of land use and (e) extract and analyse outputs of the model for estimation of WA+ variables. The modified version with the water accounting capability is called SWAT-FARS.

More details about the modifications are as follows:

- Simulating groundwater level

In the original SWAT groundwater module, the simulation is done in two series of reservoirs located below the soil layers. The given approach can be useful in groundwater simulation if the groundwater level changes are not significant. Otherwise, the SWAT model only provides an estimation of the net water volume stored in the aquifer and doesn't report the aquifer water level changes for use in model calibration (Vazquez-Amábile and Engel, 2005). Therefore, the model code was changed to simulate daily groundwater level for each study region using Eq. (2):

$$h_{wtbl,i} = h_{wtbl,i-1}.\ \exp[-\alpha_{gw}.\ \Delta t] + \frac{w_{rchrg}.\ (1 - \exp[-\alpha_{gw}.\ \Delta t])}{800.\ \mu.\ \alpha_{gw}} \tag{2}$$

where h_{wtbl} is the groundwater level (mm), α_{gw} is the time delay (days) and w_{rchrg} is the total amount of aquifer recharge (mm), μ is the aquifer storage factor and Δ*t* is the analysis time interval. The modifications for reporting the groundwater level were done in hruyr.f, hrymon.f and gwmod.f sub modules.

- **Simulating the interactions of aquifers**

The original SWAT model simulates the spatial variations of groundwater volume and depth in each subbasin's HRUs without considering the subbasin's interactions. However, it is essential to consider interactions and exchanges between aquifers in different subbasins where the aquifer boundaries do not match the boundary of subbasins (Kim et al., 2008). This feature is provided in the SWAT-FARS model by redefining the aquifer HRUs by overlaying the subbasin HRUs layer and aquifer boundaries (Fig. 2) to consider aquifer boundary and its ground water storage interaction. Redefinition of HRUs for simulation of aquifer interactions was done in irrsub.f, irrigate.f, gwmod.f SWAT sub modules.

- **Modifying the SWAT irrigation management modules**

Application of SWAT to intensive irrigation agricultural basins where irrigation processes are the major component of the hydrologic balance could not be used for water accounting due to its limitations in simulation of water losses when the irrigation source is a river or outside the watershed during irrigation events. In this case, SWAT applies irrigation depth that fills the soil layers up to field capacity. If the irrigation depth exceeds field capacity, the excess water between soil saturation and field capacity limits returns to the irrigation source and isn't considered in the daily soil water balance calculation. It is the

Table 3
Summary of the SWAT output variables, description and modification needed to produce the required WA+ variables.

WA+ sheet	Variable	SWAT output variable/ output file	Status	Description	Modification needed/subroutine
Resource base	Precipitation	PRECIP/output.sub	Av.	–	–
	Surface storage change	VOLUME/output.rsv	Av.	–	–
	Groundwater storage change	SA_ST& DA_ST/ output.hru	NA.	–	– simulation of aquifer interactions/ irrsub.f, irrigate.f, gwmod.f – reporting the aquifer water level changes/ hruyr.f, hrymon.f, gwmod.f
	Snow storage change		Av.	–	–
	Soil water storage change	SW_INIT & SW_INIT/ output.hru	Av.	–	–
	Natural evapotranspiration	ET/output.hru	NA.	Land use evaporation from non-irrigation scenario	–
	Incremental evapotranspiration	ET/output.hru	NA.	Evapotranspiration caused by irrigation agriculture minus et in non-irrigation scenario	– simulation of water losses in intensive irrigation systems/irrigate.f – applying the dynamic land use changes in model
	Basin outflow	FLOW_OUT/output.rch	Av.	–	–
Evapotranspiration	Soil evaporation	ESOL/output.hru	NA.	Soil evaporation reported as "ESOL" variable in modified swat model	reporting soil evaporation in output files/hruyr.f, hrymon.f
	Ground water evaporation	REVAP/output.hru	Av.	–	–
	Evaporation from rivers	EVAP/output.rch	Av.	–	–
	Reservoir evaporation	EVAP/output.rsv	Av.	–	–
	Transpiration of agricultural crops	Tr/output.hru	NA.	Crop transpiration reported as "Tr" variable in modified swat model	reporting transpiration in output files/ hruyr.f, hrymon.f
	Transpiration of natural plants	Tr/output.hru	NA.	Land use transpiration reported as "Tr" for each land use class in modified swat model	Reporting transpiration in output files/ hruyr.f, hrymon.f
Withdrawal	Withdrawal water	IRR/outputhru	NA.	Withdrawal water calculated by dividing IRR by irrigation efficiency for each HRU	–
	Irrigation losses	IRLOS/output.hru	NA.	Total irrigation losses reported as "IRLOS" for each land use class in modified swat model	Reporting irrigation losses in output files/ hruyr.f, hrymon.f
	Fraction of soil evaporation from incremental evapotranspiration	ESOL/output.hru	NA.	Soil evaporation losses caused by irrigation agriculture minus ESOL in non-irrigation scenario	Reporting soil evaporation in output files/ hruyr.f, hrymon.f
	Fraction of crop transpiration from incremental evapotranspiration	Tr/output.hru	NA.	Crop transpiration caused by irrigation agriculture minus transpiration in non-irrigation scenario	Reporting transpiration in output files/ hruyr.f, hrymon.f
	Return flow to surface water	GW-Q/output.hru	NA.	Return flow to surface water (GW-Q) minus GW-Q in non-irrigation scenario	–
	Return flow to ground water	GW-RCH/output.hru	NA.	Return flow to groundwater water (GW-RCH) minus GW-RCH in non-irrigation scenario	–

Av = Available and NA = Not Available.

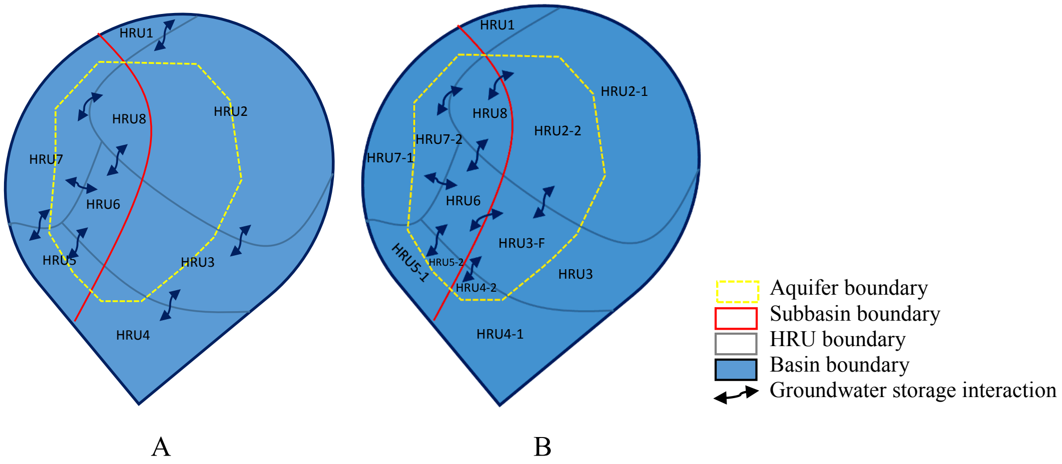


Fig. 2. Revisions to HRU groundwater storage interaction in SWAT-FARS. These revisions are illustrated within a simplified subbasin. (A) The standard SWAT subbasin and HRUs ground water storage interaction. (B) Redefinition of HRUs boundaries, which conform to the aquifer boundary and its ground water storage interaction in new configuration. Using the new HRU definition, ground water storage from HRUs 8 and 6 and fraction of HRUs 2, 3, 4, 5 and 7 can be exchanged.

same in the case of irrigation losses as well. Irrigation losses are defined as water that leaves the system without a benefit for agricultural crop growth that includes the conveyance and application losses. The conveyance losses relate to water transport losses from the source to the field. The application losses also relate to the portion of irrigation water that lost through the water application on field including soil evaporation and other non-beneficial components (e.g. weed transpiration and evaporation from conveyance systems). The conveyance and application losses affect irrigation efficiency which is defined as the ratio between water consumption (plant evapotranspiration) and water withdrawal from water resources including rivers, reservoirs, lakes, or groundwater (Jägermeyr et al., 2015). For the application of SWAT in intensive irrigation (application of water to maintain standing water on the field) agricultural basins, the irrigation subroutine source code needs to be modified to consider the irrigation losses.

In this study, to include the excess water in the soil water balance calculations, the SWAT irrigation modules were modified based on a modification proposed by Dechmi et al. (2012). According to previous research works, about 35 to 50% of water withdrawal volume from water resources for irrigation returns to groundwater resources (Nasri et al., 2015; Dor et al., 2011; Arumí et al., 2009) and the real water losses have been reported in general at about 5% to 20% (Karimi et al., 2013b; Foster et al., 2009; Keller and Keller, 1995). Due to the water conveyance systems in surface irrigation, water conveyance and application losses are higher than water losses in groundwater irrigation and the surface irrigation efficiency is less than the groundwater irrigation efficiency. To consider accurate water losses, information and values reported by other researchers (e.g. Kienzle and Schmidt, 2008; Foster et al., 2009) were considered. In this study, the application water losses of irrigation events from surface water and groundwater resources are considered to be 20% and 10% of conveyance losses, respectively, which is added to the actual evapotranspiration of the corresponding HRUs. In this section modifications were done in sub modules including irrsub.f, irr_res.f, subbasin.f and gwmod.f.

- **Applying the dynamic changes of land use**

One of the important points in the simulation of agricultural basins relates to update the land-use status of basins during the simulations. SWAT-FARS model, automatically integrates multiple land use maps and prepares the input files necessary for activating the land use update (LUU) module in SWAT-FARS. For this, HRU fractions are updated at the given times based on the changing of area and location of land use.

- **Generation of** WA+ **sheets based on the SWAT model outputs**

Various outputs of the model are required to be extracted and get processed to produce the required information of WA+ framework. So, SWAT-FARS interface was developed (in C# programming language) for this task. The interface is capable to run modified SWAT model and extract and calculate the WA+ variables by processing the output files of the SWAT model in each land use type and study region for annual and monthly time scales. Fig. 3 shows the SWAT-FARS package main window.

- **Real water saving concept**

One the main applications of this system is to explain impacts of different measures on water saving. SWAT-FARS emphasizes the concept of 'real water saving' (Seckler, 1996). It means, when a policy is effective it reduces 'Incremental evapotranspiration' and such water savings may be allocated to other uses, or increase system 'Outflows'.

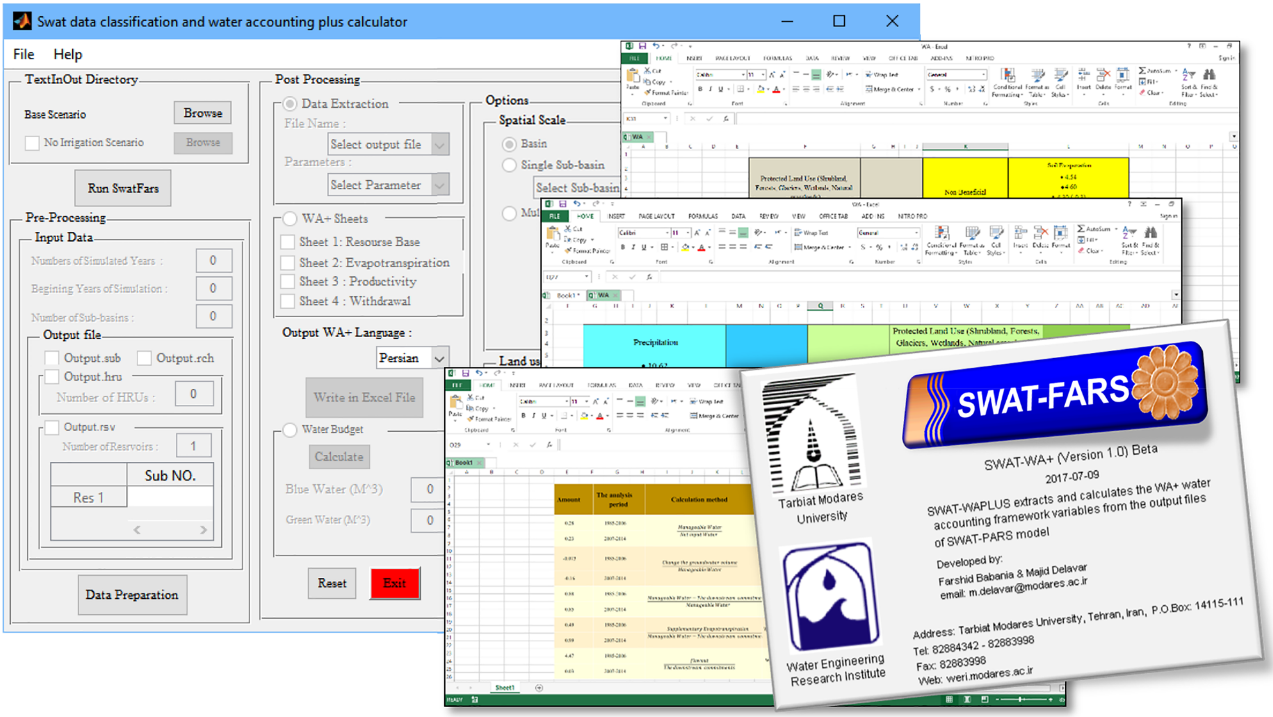
3. Results and discussion

This section explores SWAT-FARS setup and its capabilities for analyzing water resources status and management scenarios based on the WA+ water accounting framework through the Tashk-Bakhtegan basin.

3.1. Paramertization of SWAT-FARS model

For this part, Tashk-Bakhtegan basin was divided into 56 subbasins and 2245 HRUs. HRUs were extracted using the Digital Elevation Model (DEM), soil, land use layers that have homogeneous slope, land use, and soil characteristics. The DEM layer was obtained from ASTER with 30 m resolution and the soil map from the FAO (2011). Also, three land use maps for 1987, 2007 and 2015 (WRI, 2015) and locations of rivers, hydrometric stations, dams, and study regions (i.e. CUs) were prepared as well. Furthermore, the management information relating to irrigation sources and irrigation planning, the operation of three existing dams, crops planting/harvesting dates, application of fertilization and pesticide are prepared from the local organizations.

The next step is the sensitivity analysis of model parameters that was used to determine which parameters have the largest impact on each outputs of the model. Sensitivity analysis, calibration and uncertainty analysis of the SWAT-FARS model are performed with SWAT-CUP model (Abbaspour, 2015) using Sequential Uncertainty Fitting



Numbers of Simulated Years : 0
Begining Years of Simulation : 0
Number of Sub-basins : 0
Number of HRUs : 0
Number of Reservoirs : 1
Output WA+ Language : Persian
Blue Water (M^3) 0
Green Water (M^3) 0

SWAT-WA+ (Version 1.0) Beta
2017-07-09
SWAT-WAPLUS extracts and calculates the WA+ water accounting framework variables from the output files of SWAT-PARS model
Developed by:
Farshid Babania & Majid Delavar
email: m.delavar@modares.ac.ir
Address: Tarbiat Modares University, Tehran, Iran, P.O.Box: 14115-111
Tel: 82884342 - 82883998
Fax: 82883998
Web: weri.modares.ac.ir

Fig. 3. The SWAT-FARS package main windows.

Table 4
Summary of sensivity analysis and t-stat and p-value on the parameters of SWAT-FARS model.

Rank	Parameter	Definition	t_Stat	P-value	Initial range	Final range
1	CN2.mgt	SCS runoff curve number	− 42.09	0.00	40–90	53–79
2	GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow	25.21	0.00	100–2000	650–1250
3	SOL_Z(1).sol	Thickness of first soil layer	4.16	0.00	(−0.5)−0.5	(−0.32)−0.05
4	SOL_Z(2).sol	Thickness of second soil layer	2.20	0.03	(−0.5)−0.5	(−0.32)−0.05
5	ALPHA_BF.gw	Base flow alpha factor	− 2.16	0.03	0.01–1	0.04–0.42
6	TLAPS.sub	Temperature gradient	1.45	0.15	(−8)−(−5)	(−7.5)−(−5.8)
7	SOL_K (..) .sol	Hydraulic conductivity of soil	− 0.83	0.41	(−0.5)−0.5	(−0.11)−0.24
8	SOL_AWC (..) .sol	Available water capacity of the soil layer	− 0.75	0.45	(−0.5)−0.5	(−0.22)−0.37
9	GW_DELAY.gw	Groundwater delay	− 0.73	0.46	1–60	12–47
10	SFTMP.bsn	Threshold temperature of Snowfall	− 0.71	0.48	(−0.5)−3	0.2
11	SMTMP.bsn	Threshold temperature of Snow melt	0.49	0.62	(−0.5)−3	0.5
12	PLAPS.sub	Annual precipitation gradient	0.45	0.65	(−0.2)−0.2	(−0.03)−0.18
13	GW_REVAP.gw	groundwater Evaporation coefficient	0.20	0.84	0–0.2	0.01–0.07
14	REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur	0.19	0.85	100–2000	700–1300

Algorithm (SUFI-2). For example, Table 4 indicates the parameters as well as p-value and t-stat, initial and final range of them in the stream flow calibration process. Each parameter which has more t-stat value and if its p-value is close to zero, has had the largest impact on streamflows. Therefore, the results showed that CN2 parameter (Curve Number Parameter) was the most sensitive parameter and after that GW-QMN. These parameters were effective ones on surface runoff and groundwater participation in streamflow.

3.2. *Calibration and validation of the SWAT-FARS model*

SWAT-FARS needed further calibration and validation, what we called it as “multi-variable & multi-site calibration”. Since, the conventional reliance on hydrometric data is insufficient and it is crucial to include other processes and especially actual evapotranspiration in the course of calibration. For this aim, the model calibration and validation were carried out using maximum available observation data such as (1) river discharges, (2) groundwater level, (3) base flow, (4) potential and actual evapotranspiration and (5) crop yields. To do this, after the initial setup of the model, calibration and validation were carried out in a multi-stage process. In the first step, hydrological calibration was performed using stream flow, base flow, and groundwater level to ensure the model simulates surface water, groundwater and their interacting. In the next step, potential and actual evapotranspiration and crop yields were calibrated. For more clarification, the calibration and validation process of SWAT-FARS is shown in Fig. 4.

Fig. 5 shows performance of the calibrated model for simulation of stream flows (a), base flows (b) and groundwater level (c) using the statistical indices including the coefficient of determination (R^2) and Nash-Sutcliffe efficiency coefficient (NS).

The calibration (during 1985–2006) and validation (during 2006–2014) of surface runoff and its base flow were performed using the more important parameters as shown in Table 4. Fig. 5(a) shows the values of the coefficient of determination (R^2) and Nash-Sutcliffe efficiency coefficient (NS) are more than 0.5, which indicate an acceptable model performance for stream flow simulation in the calibration and validation periods.

In order to evaluate the results of base flow simulation, two correlation features for observed and simulated base flow and base flow index were considered. In this study, two sub programs called BFI+ in

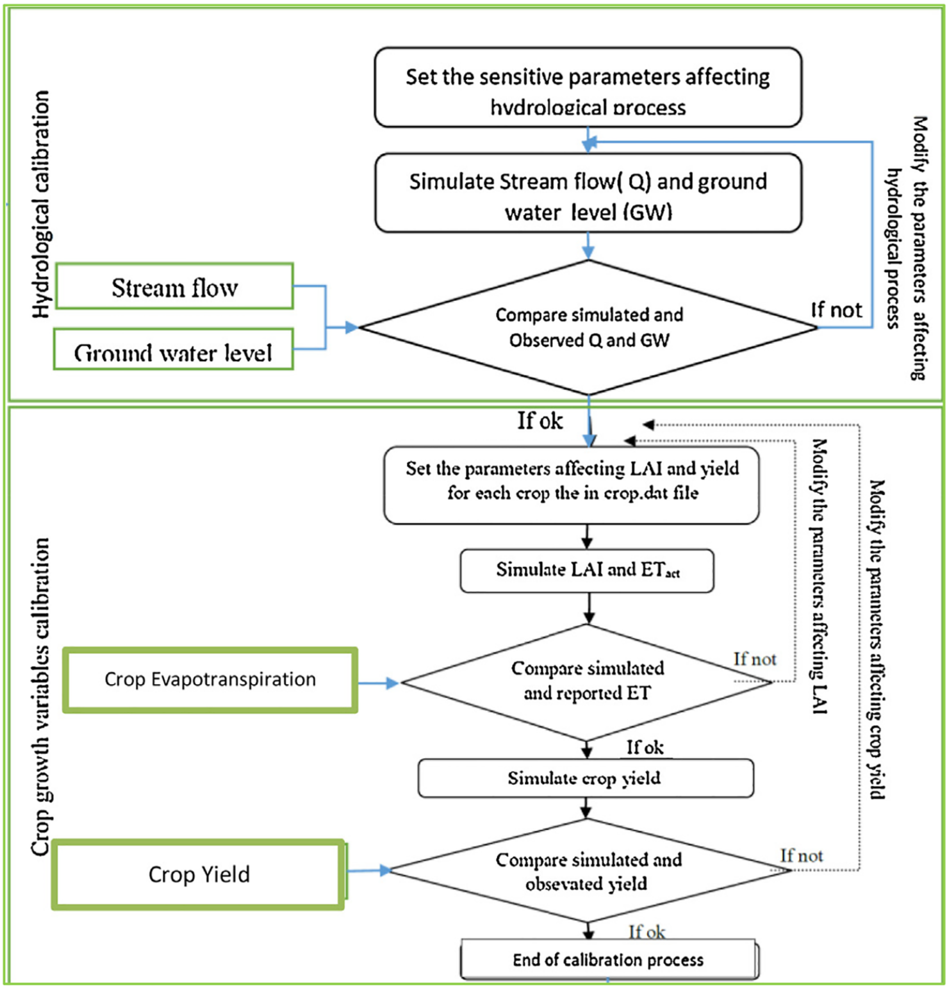


Fig. 4. Framework for the model calibration and validation process.

Hydro Office software (Gregor, 2012) and Recursive Digital Filter method were applied to separate base flow from the daily streamflows. The separation was done for the stations that were not affected by the upstream controlled flows for 1985 to 2014 (i.e. Dehkade-Sefid, Jamalbeig-Shirin, Tange-Balaghi and Droudzan stations). As shown in Fig. 5(b) the results of monthly base flow evaluation at these stations indicate an acceptable performance of the model (R^2 between 0.88 and 0.95 and Nash coefficient between 0.56 and 0.73).

Finally, Fig. 5(c) shows the model performance for simulating the groundwater level changes in each aquifer. The values of R^2 and NS indices for the calibration and validation of groundwater level changes are more than 50% in 83% and 87% of these aquifers, respectively. Also, the maximum deviation between simulated and observed values is about 26%. The results indicate the acceptable performance of the model in simulating aquifers volume changes in most study regions.

Due to the importance of proper simulations of actual evapotranspiration (ETa) (and crop yields as an indicator for Eta) to evaluate the basin water consumption through different management scenarios; efforts were made to calibrate this crucial variable. However, since there is no direct measurements for ETa in the basin (a common problem), the average simulated ETa under full irrigation (i.e. maximum crop water requirement) is compared to values reported by the Iran National Water Document (2007). This document includes different crop water requirements of all the basin within Iran. The calibration of the model for crop yields was also simultaneously carried out with calibration of actual evapotranspiration. Fig. 6 shows the box plot of the observed values of evapotranspiration and crop yields in comparison with the average simulated values. The results indicate that there is an acceptable agreement between the model results and the observed values according to maximum and minimum values in the range changes and first and third quartiles. As seen in Fig. 6, except for tomato and bean, the average simulated evapotranspiration of the crops are varied from the first to third quartile of the observed values. Also, it is shown that the average simulated crop yields are within the first to third quartile of the observed values.

3.3. *Water Accounting Plus (WA$^+$) based on the SWAT-FARS model*

Based on the calibrated model and further linkage to WA+ framework, the water accounting sheets are presented for the two periods of time including: 1985 to 2006 (1st) and 2007 to 2014 (2nd). Dividing of the entire period in two sections is based on Farokhnia (2016) that reported prolong droughts and significant changes on the hydrological characteristics after 2006. Using these sheets, status of the basin's water resources issues are assessed and presented in the following sections. Additionally, the results for the entire record (i.e. 1985–2014) are also illustrated in the sheets to show more the flexibility of the developed system.

3.3.1. *WA+ resources base sheet*

The first sheet is the resource base sheet (Table 2) and is shown in Fig. 7. The sheet shows how the components are varied during the first and second periods as well as the entire time period. The major difference related to 'Net inflow' originated from decreases in the basin's

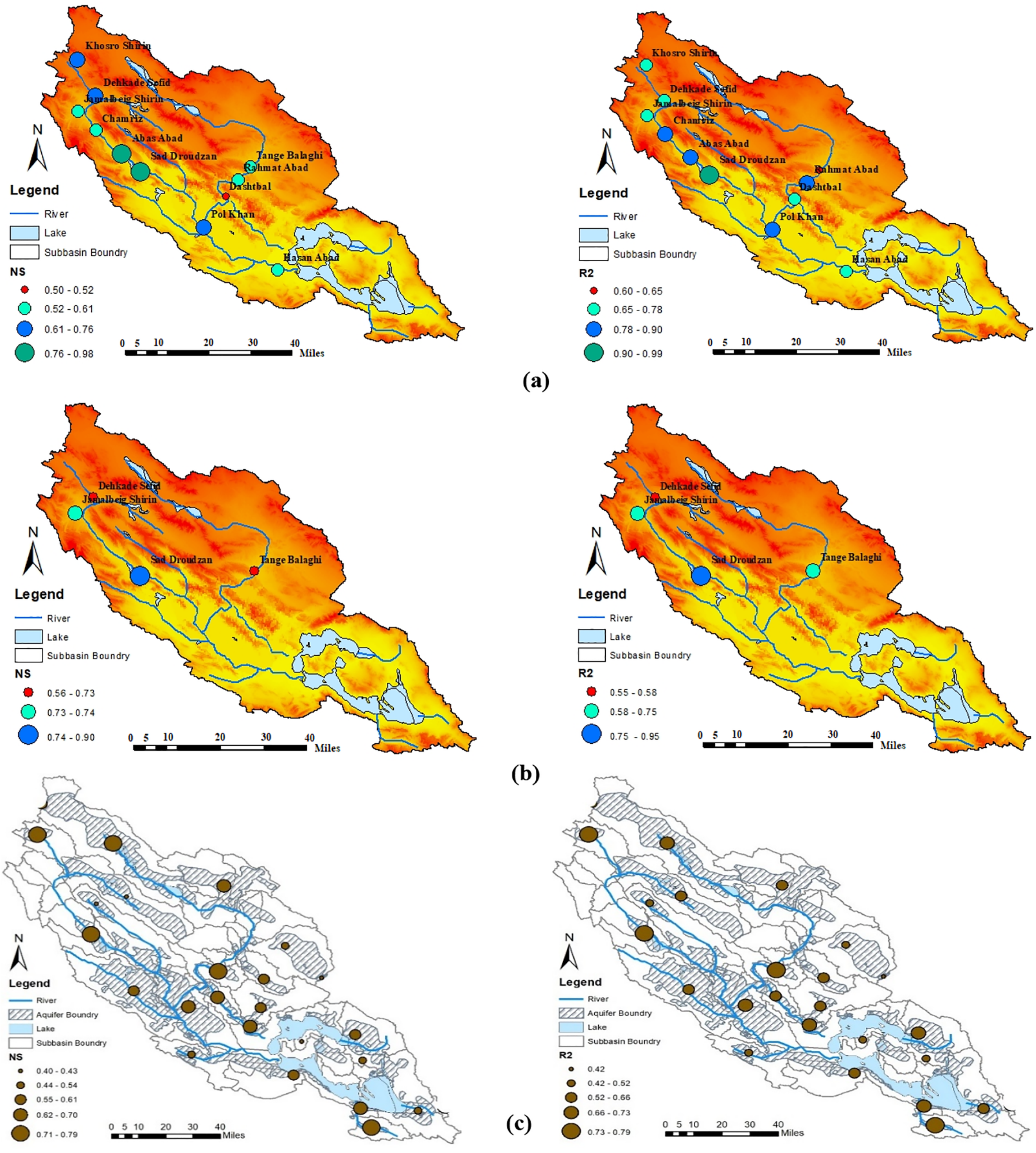


Fig. 5. Summary of model performance evaluation for simulating of stream flows (a), base flows (b), groundwater level (c) in the total calibration and validation periods.

precipitation. The sheet shows about 5% decrease in the ‘Precipitation’ and 10% decrease in ‘Net inflows’ during the two time periods. It is also affected by the changes in surface water and groundwater reservoirs, snowpack, and soil moisture. During the investigated periods, the natural evapotranspiration as one of the most important outflows has decreased by about 4.3%, which is mainly due to precipitation decrease. However, changes in ‘Manageable water’ is more critical. A decrease of 23% is reported in the sheet from the first period to the second period for ‘Manageable water’ along with an increase of ‘Incremental evapotranspiration’ of about 53%. This substantially relates to an increase of cropped lands and increase of the basin’s temperature (Farokhnia, 2016). These changes have led to a significant shortage of environmental flows such that the inflows of Tashk-Bakhtegan lakes are decreased from 1.47 to 0.01 billion m^3/yr.

3.3.2. *Evapotranspiration sheet*

Fig. 8 shows the evapotranspiration sheet (Table 2) for the time periods. The amounts of water consumption for different land uses are

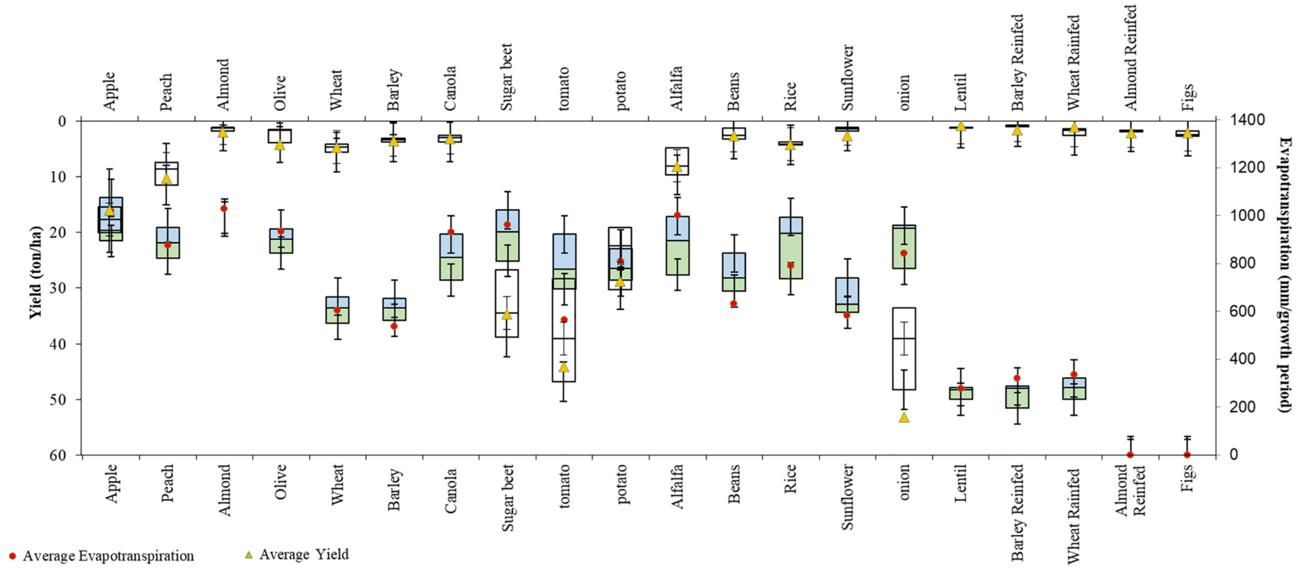


Fig. 6. Comparison of the observed values of evapotranspiration (colored box plot) and crop yield (white box plot) with the simulated values of average Evapotranspiration (red points) and yield (yellow points). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

presented on the left. The figure shows 38% increase of ETa of 'Managed land use' as the most significant component to show the role of human activities on water consumption. The right side of the report shows 'Beneficial' and 'Non-beneficial' water consumptions. In this part, beneficial evapotranspiration is considered as transpiration of crops and natural plants. While non-beneficial evapotranspiration occurs through evaporation from soil, reservoirs, etc.

The sheet also reveals that despite of the significant reduction in 'Manageable water' (Fig. 7), 12% increase in 'beneficial evapotranspiration' is simultaneously occurred. It can be attributed to the increase in cultivated areas and substitution of high water consuming plants in the cropping pattern that has increased transpiration of plants up to 30%. Also, transpiration of natural plants (e.g. pastures and forests) are decreased about 13% due to a partial reduction in the area and less available moisture as reduced precipitation. In case of the non-beneficial evapotranspiration; soil evaporation as one of the biggest source of consumption is about 4.5 BCM (almost 84% of the total consumptions) that is reduced by 6.5%. This shows although, increasing in agricultural area and irrigation practices increased soil evaporation, but the negative effect of precipitation decline on it has been great. The evaporation from water bodies (dams and lakes) is another component of the non-beneficial evapotranspiration that indicates 50% increase between the periods of time. This increasing is also due to Mullah Sadra dam impoundment in the second period. Groundwater evaporation also indicates a slight increase in the second period.

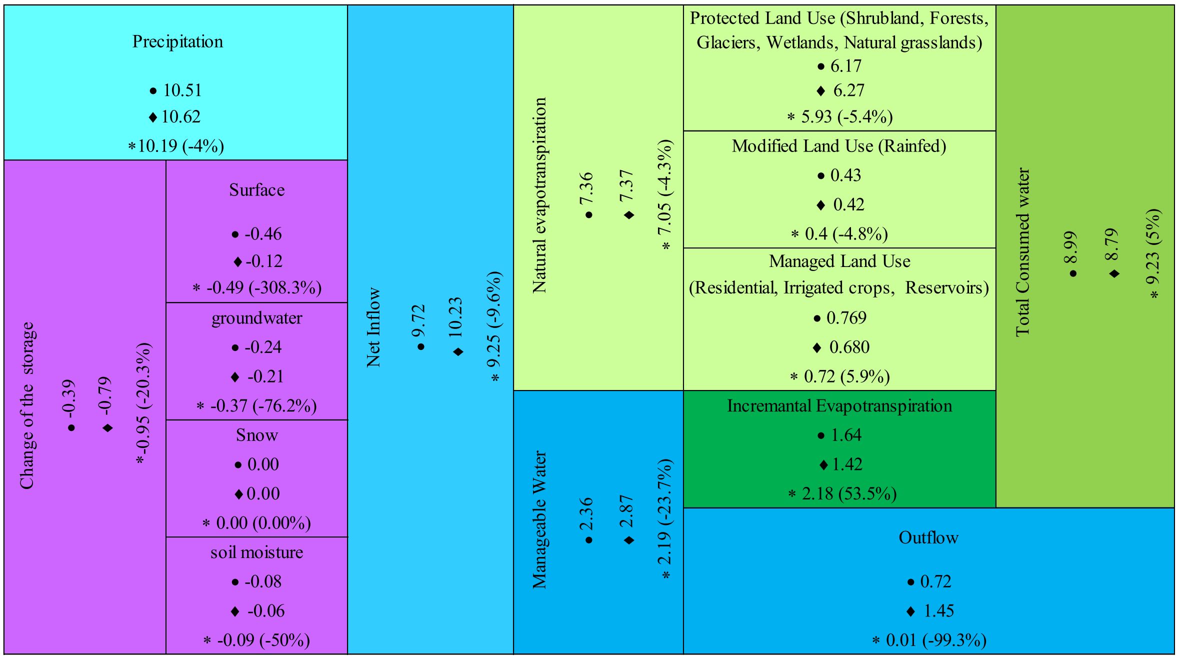


Fig. 7. WA+ resource base sheet (BCM/yr) for the time periods of 1985–2006 (♦), 2007–2014 (*) and 1985–2014 (•). (The values (%) in parentheses indicate the changes from 1985 to 2006 to 2007–2014).

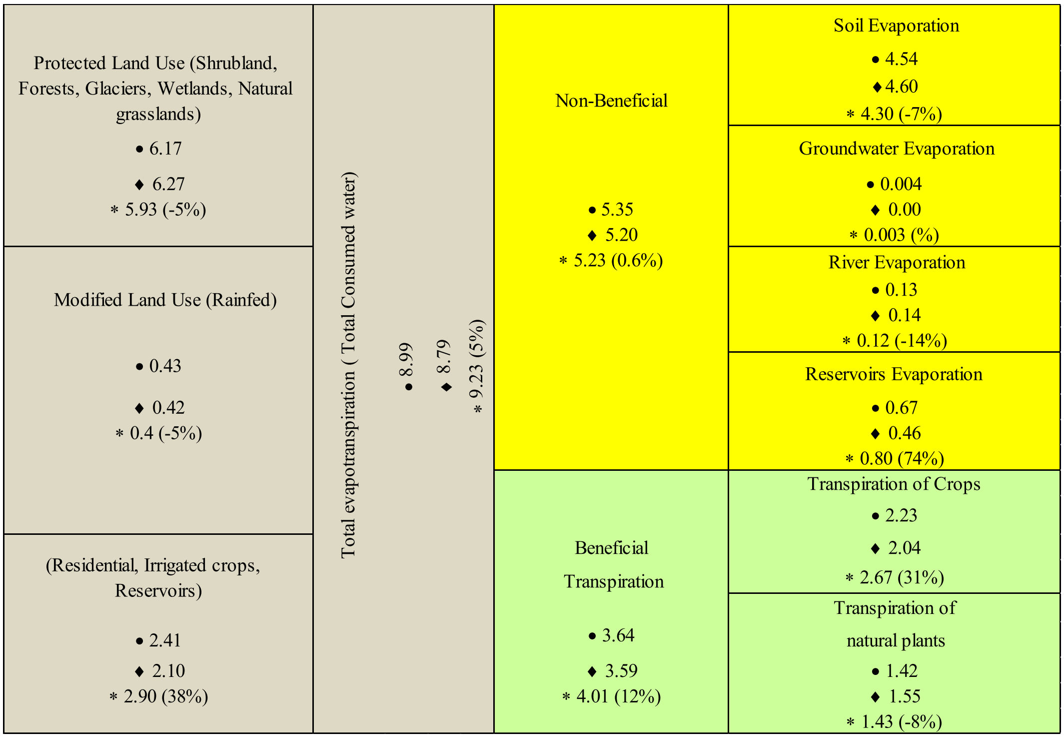


Fig. 8. WA+ evapotranspiration sheet (BCM/yr) for the time periods of 1985–2006 (♦), 2007–2014 (*) and 1985–2014 (•) (The values (%) in parentheses indicate the changes from 1985 to 2006 to 2007–2014).

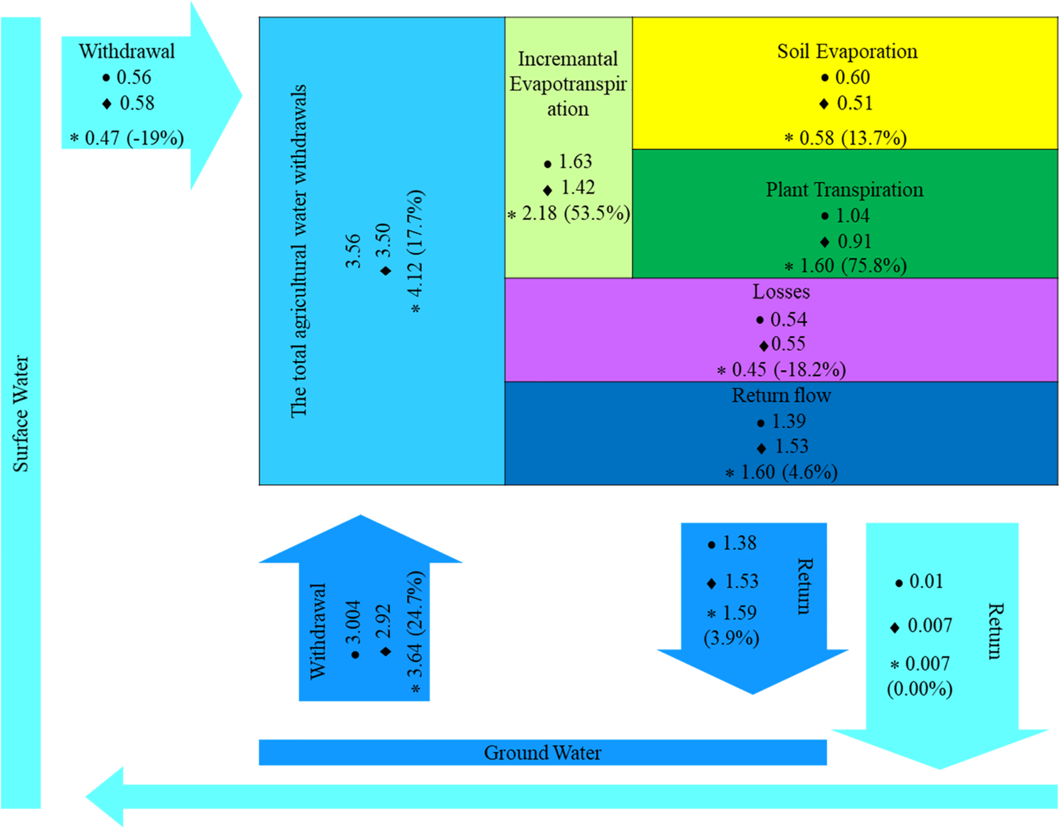


Fig. 9. WA+ withdrawal sheet (BCM/yr) for the time periods of 1985–2006 (♦), 2007–2014 (*) and 1985–2014 (•) (The values (%) in parentheses indicate the changes from 1985 to 2006 to 2007–2014).

3.3.3. Withdrawal sheet

Fig. 9 shows the withdrawal reporting sheet (Table 2). Due to increasing production in the irrigated area, the total agricultural water withdrawals and agricultural groundwater withdrawals in the second period increased by 17.5 and 24.6%, respectively. The lack of surface water resources in the second period, especially in downstream regions, can be one reason for 17% decrease in surface water withdrawals. Therefore, incremental evapotranspiration and losses increased by 34% for the second period. Conveyance and application losses of irrigation water have been increased from 450 million m^3 to 556 million m^3 (almost 11% increase) due to increase in water withdrawals (particularly increasing in surface water withdrawals are associated with larger losses due to transmission and issues related to surface irrigation networks).

The last part of this report deals with the amount of withdrawn water returned to the surface and groundwater sources, which is not sufficiently considered in many studies. The returns to the surface and groundwater sources is considered as loss in the analysis of classical irrigation efficiency where it has not been removed from water basin cycle and it can be recoverable and reusable (Keller and Keller, 1995).

The results show that approximately 38% of the water withdrawals for irrigated agricultural lands in the Tashk-Bakhtegan basin returns to surface water and groundwater resources. The total return flows have been increased almost 36% in the second period due to increasing in water withdrawals over time. The return flows to groundwater resources is up to 98% of total return flows.

3.3.4. WA^+ performance indicators

Table 5 shows the indicators of each reporting sheet along with their descriptions and the amount of them in the two analyzing periods. For calculations of some the indicators in the resource base sheet, it was necessary to consider the environmental water right of the Tashk-Bakhtegan Lake as 'Committed flow', which is 342 million m^3/yr in normal conditions (Fars Province Department of Environment, 2011).

The indicators of Water Resources and Consumptions report, respective definitions and amounts for the two periods are presented in Table 5. For instance, it is illustrated that the ratio of 'Manageable water' was 28% in the first period and decreased to 23% in the second period, which is mainly due to decrease in precipitations. Similarly, the ratio of 'Groundwater resources change' increased from 7.3% to 16% in the second period that indicates more over-exploitation of groundwater. The ratio of 'Utilizable water' for the first period indicates 88% of water allocable in the basin is used for consumption and, simultaneously, supplying downstream commitments (about 342 million m^3 as the water rights of the lakes in normal conditions). But in the second period, it decreases to 85% of basin available water and almost no inflows to the lakes (the ratio of 'Commitments downstream supply' equals 4.47 and 0 for the periods, respectively). Another notable ratio is the 'Consumption ratio', which is 49% for the first period. It indicates only 50% of allocable water was being consumed during the first period. However, it increased to 99% in the second period in which the exploitation of water resources is more than the manageable water.

3.3.5. Spatial and temporal evaluation of WA+ components

One of the main expectations from water accounting analysis is the ability to evaluate and identify trends in water supply, demand, accessibility and use in time and space within specified domains (FAO, 2012). Definitely, providing such information and respected records are very limited or not available at all. This option is embedded in SWAT-FARS and the components of WA+ are possible to be extracted at different scales and time. For instance, Fig. 10 shows spatial variation of 'Total consumed water' (Water resources and consumptions sheet) within the basin. Fig. 11 also illustrates temporal variation of 'Precipitation', 'Total consumed water' and 'Outflow' (Water resources and consumptions sheet) during 1985 to 2014. The behavior of the basin before 2004 and after it noticeable. Moreover, based on Batchelor et al.

Table 5

Extracted indicators from the reports of the WA+ framework for different time periods.

Index	Description	Calculation method	Period	Amount
water sources and consumptions				
The ratio of manageableWater	What proportion of net input basin is programmable for consumption and downstream commitments?	$\frac{\text{Manageable Water}}{\text{Net input Water}}$	1985–2006 2007–2014	0.28 0.23
The ratio of ground water resources change	What proportion of basin manageable water is originated the change volume of groundwater?	$\frac{\text{Change the groundwater volume}}{\text{Manageable Water}}$	1985–2006 2007–2014	−0.073 −0.16
The ratio of utilizable water	What proportion of basin available water is used for consumptions within basin?	$\frac{\text{Manageable Water} - \text{The downstream commitments}}{\text{Manageable Water}}$	1985–2006 2007–2014	0.88 0.85
Consumption ratio	What proportion of basin available water is consumed on it?	$\frac{\text{Supplementary Evapotranspiration}}{\text{Manageable Water} - \text{The downstream commitments}}$	1985–2006 2007–2014	0.49 0.99
The ratio of commitments downstreamSupply	What proportion of water commitments the downstream basin is supplied?	$\frac{\text{flowout}}{\text{The downstream commitments}}$	1985–2006 2007–2014	4.47 0.03
Evapotranspiration				
Transpiration ratio (beneficial consumption of basin)	What part of the basin evapotranspiration has been spent for the plants Transpiration? (How much the water consumptions of basin has been beneficial?)	$\frac{\text{The Total Transpiration}}{\text{The Total Evapotranspiration}}$	1985–2006 2006–2014	0.41 0.43
Agriculture Transpiration ratio (beneficial consumption of agriculture sector)	What part of agricultural evapotranspiration has been spent for the plants Transpiration? (How much of agricultural water use has been beneficial?)	$\frac{\text{Agriculture Transpiration}}{\text{Total agricultural evapotranspiration}}$	1985–2006 2006–2014	0.81 0.81
Manageable area consumption ratio	What part of basin water consumption have happened in the lands under management?	$\frac{\text{Evapotranspiration of managed lands}}{\text{The Total Evapotranspiration}}$	1985–2006 2006–2014	0.23 0.31
Agricultural Evapotranspiration ratio	What part of basin water consumption has been spent agricultural production?	$\frac{\text{Agricultural Evapotranspiration}}{\text{The Total Evapotranspiration}}$	1985–2006 2006–2014	0.23 0.28
Irrigated Agricultural Evapotranspiration ratio	What part of the agricultural water use of basin has been supplied Through irrigation?	$\frac{\text{Irrigated agricultural evapotranspiration}}{\text{Agricultural Evapotranspiration}}$	1985–2006 2006–2014	0.83 0.87
Withdrawal				
Groundwater Withdrawal ratio	What part of the total water withdrawal for irrigation have been from basin groundwater?	$\frac{\text{groundwater Withdrawal}}{\text{The total agricultural water withdrawals}}$	1985–2006 2006–2014	0.56 0.88
Farm Efficiency	What part of the water withdrawal for irrigation has been spent crop evapotranspiration?	$\frac{\text{Incremantal Evapotranspiration of irrigated lands}}{\text{The total agricultural water withdrawals}}$	1985–2006 2006–2014	0.40 0.45
Basin Efficiency	What part of the water used to irrigate has been spent the crop evapotranspiration?	$\frac{\text{Incremantal Evapotranspiration of irrigated lands}}{\text{The total agricultural water withdrawals - Return Water}}$	1985–2006 2006–2014	0.73 0.85
The Return Water ratio	What part of the water withdrawal for irrigation is back again to the water resources of basin?	$\frac{\text{Return Water}}{\text{The total agriculturalwater withdrawals}}$	1985–2006	0.43

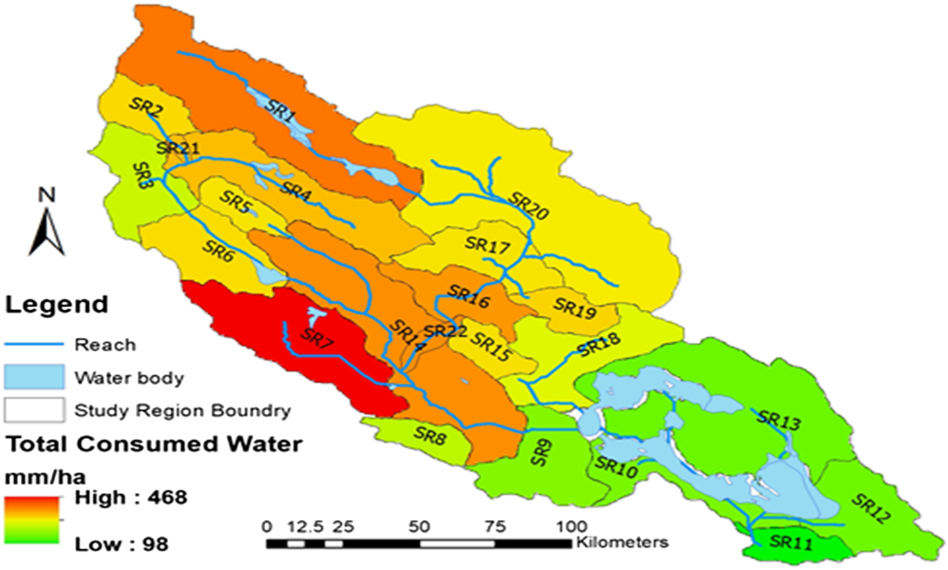


Fig. 10. Spatial pattern of average of 'Total consumed water' in the study regions during (1985–2014).

(2016) through water accounting it would be possible to underlying causes of imbalances in supply and demand and levels of environmental sustainability. Fig. 11 shows also status of the basin from these point of views as well. Although, more detailed information can be obtained from the sheets to address these issues.

3.3.6. *Application of SWAT-FARS for analyzing the management policies*

Water saving and alleviating pressure on water resources are the common goals in the environmental section of the Iran 6th five-year development plan. For this aim, 'changing cropping pattern' and 'changing irrigation from surface to pressurized systems' has attracted the most attentions as possible solutions. These policies are evaluated for the study area as follows:

- *Changing cropping pattern*

Rice is a high consuming water crop and based on the 6th plan; it is suggested to eliminate this practice from the Tashkh-Bakhtegan basin's cropping pattern. The current rice area in the basin is about 30,000 ha out of 450,000 ha of the irrigated area. To assess effects and side effects of such a policy, all the rice HRU's substituted by wheat in SWAT-FARS and the model was run for the period of 1985 to 2014. To shorten the text, the results of the WA+ withdrawal sheet is only presented in Fig. 12. As it is shown in the figure, this management scenario reduces 'Agricultural withdrawal' by 0.27 BCM/yr (3.56 minus 3.29 BCM/yr). But, the 'Incremental evapotranspiration' and 'Transpiration' are only reduced by 0.11and 0.08 BCM/yr, respectively.

One the unique features of SWAT-FARS is the possibility to track rebound effects. In real world, when a water saving measure is implemented, the expected saved water does not necessary would be availed for another users (e.g. environment). Since it can be unintentionally applied for conventional deficit irrigation or intentionally used for development of cropped lands as well as cultivation of more water consuming crops (Raeisi et al., 2019). What has shown in Fig. 12 is based on not controlling rebound effect. Because, it needs huge infrastructure to control rebound effect and it is not available in the study area.

- *Application of pressurized irrigation*

Changing the current surface irrigation to drip system is another common policy to reduce water consumption. It is also mandated in the 6th plan which also needs huge investment. Applying this system for the entire basin shows this measure can reduce 'Agricultural withdrawal' by 1.25 MCM (3.56 minus 2.31BCM/yr). Notably, this measure not only decreases 'Incremental evapotranspiration' and 'Transpiration', but also increases them by 0.15 and 0.25 BCM/yr, respectively due to reduction of deficit irrigation when more water is

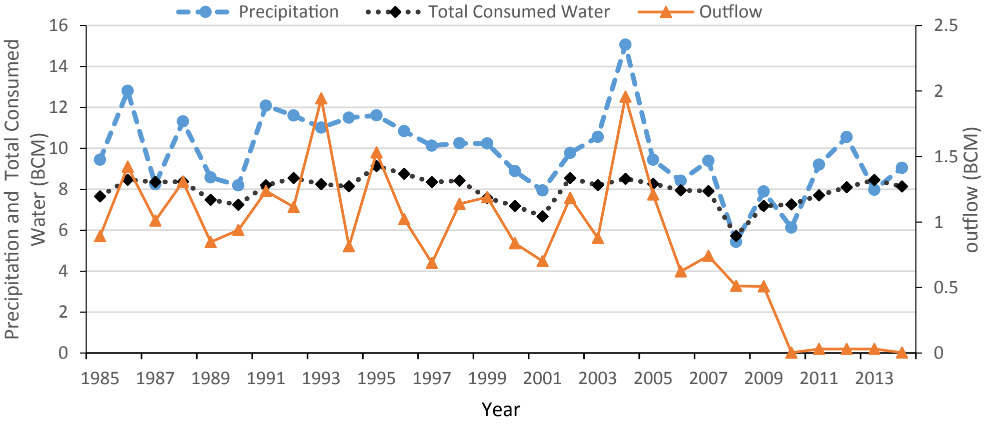


Fig. 11. Temporal pattern of 'Precipitation', 'Total consumed water' and 'Outflow' (Water resources and consumptions sheet) during 1985 to 2014.

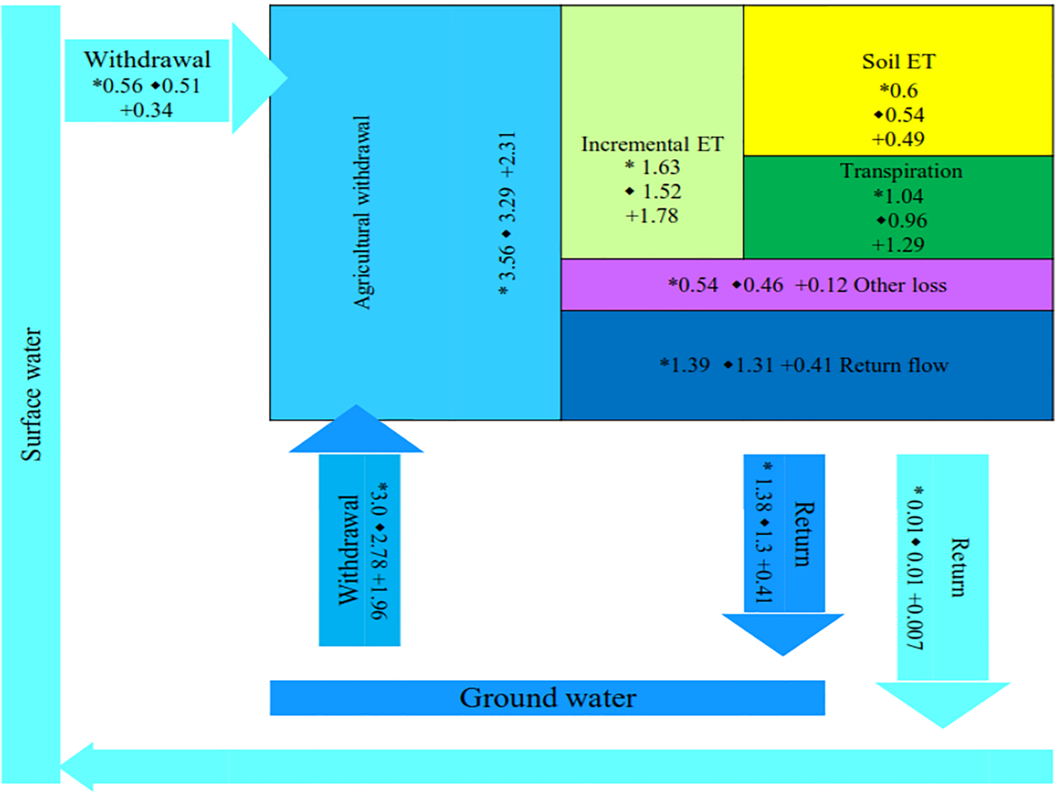


Fig. 12. Changes of WA+ withdrawal sheet (BCM/yr) in three management scenarios during 1985–2014, including: (*) Base scenario, (◆) Substitution of wheat by rice in the cropping pattern and (+) Changing irrigation system from surface to drip.

available (Fig. 12). This issue is warned in Perry et al. (2017) that as far as water allocation is not controllable, increasing irrigation efficiency can have negative effect on water consumption.

4. Conclusion

The aim of this research work was to enhance capabilities of WA+ water accounting with linkage to SWAT as a conceptual model for better policy and decisions making in water resources management. For the linkage, it was necessary to make some changes in the model's code and also define new boundaries (for category units or study regions) in the package, so called SWAT-FARS. The most important philosophy behind SWAT-FARS is to develop a tool with the following concerns:

- A tool to support integrated water resources management (IWRM);
- Systematic presentation of the current status and past trends in water supply and demand as well as future situation under different policies and management scenarios through water accounting framework;
- Evaluation of effect and side effects of water policies in an integrated framework;
- Incorporation of climate scenarios (e.g. climate changes AOGCM data and historical climate trends) in management scenarios;
- Evaluation of the above assessments in different geographical domains;
- Possibility to estimate water saving using “real water saving” concept;
- Evaluation of policies under conditions of control or not control of ‘rebound effect’;
- Estimation of water and soil productivity indices based on water ‘withdrawal’ and ‘consumption’ as well as ‘beneficial’ and ‘non-beneficial’ consumption;
- Separation of climate and human effects through WA+ framework;
- Explanation of ratio of ‘actual evapotranspiration’ to maximum crop water requirements (i,e. deficit irrigation);
- Reporting the WA+ sheets at the different spatial scales from HRU level to basin level.

Application of SWAT-FARS for Task-Bakhtegan basin showed despite of a significant decrease in ‘Manageable water’ (almost 23%) due to the negative trends in precipitations; not only ‘Incremental irrigation’ in the basin is not reduced, but also it has been considerably increased (almost 53%). This has led to almost 99% decrease in outflows that eventually creates inflows to the Tashk and Bakhtegan lakes. Also, 77% decrease in the volume of groundwater resources in the basin due to over-exploitation is another consequent.

Two alleviate pressures on the basin's water resources, two main policies are considered based on the 6th developing plan. They are elimination of rice cultivation with its own social oppositions and improving pressurized irrigation with huge investment requirements. The results showed changing cropping pattern can reduce water consumption by 0.08 BCM/yr. But, changing irrigation system can even increase water consumption by 0.25 BCM/yr.

Finally, the methodology that applied to develop SWAT-FARS Package (i.e. linkage of a conceptual model- having high simulation abilities, with a relevant water accounting framework) acts a useful integrated tool to support: more realistic policy and decision making, better understand of the current state of water resources and predict future challenges and opportunities that is strongly recommended for other regions suffering water scarcity.

CRediT authorship contribution statement

M. Delavar: Conceptualization, Methodology, Software, Writing - review & editing. **S. Morid:** Conceptualization, Methodology, Writing - review & editing. **R. Morid:** Data curation, Methodology. **A.**

Farokhnia: Conceptualization, Investigation. **F. Babaeian:** Writing - original draft, Visualization, Writing - review & editing. **R. Srinivasan:** Validation, Writing - review & editing. **P. Karimi:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Definitions of WA^+ terms:

Water withdrawal: is the amount of water applied from surface water and groundwater resources.

Water applied: is the amount of consumed water, return flows and losses.

Consumed water fraction: the part of the water applied that is evaporated and transpired. It also indicates which parts of consumed water are beneficial and non-beneficial within the basin.

Beneficial water consumption: is the amount of consumed water for transpiration of natural plants and agricultural crops.

Non-beneficial water consumption: indicates the water consumed that is lost from the system through interception, soil evaporation, groundwater evaporation, and evaporation from water surfaces like rivers and reservoirs as well as weed transpiration and evaporative conveyance systems.

Return flows: the difference between applied and consumed water that describes the amount of it that is recoverable and non-recoverable.

Recoverable flow: return flows that are reused for example return flows to a water source (drains and rivers) and percolation from irrigated lands into freshwater aquifers

Non-recoverable flow: it is lost to further use due to degradation through nutrient leaching and salinity for example flows enters the ocean or brackish water bodies including percolation into saline aquifers, drains without downstream diversion, non-recoverable sinks physically or economically.

Irrigation water losses: non-recoverable return flows of the non-consumed water fraction as well as non-beneficial evaporation. Irrigation water losses are defined as water that leaves the system without a benefit for agricultural crop growth that includes the nominal and real losses.

The nominal losses: relate to water transport losses from the source to the field (conveyance losses).

The real losses: relate to the portion of water irrigation that lost through the water application on field including soil evaporation and other non-beneficial components (e.g. weed transpiration and evaporative conveyance systems).

Gross inflow: indicates the amount of water flows into the basin including precipitation, water inflows from surface or ground water resources.

Net inflow: is the amount of gross inflow after changes in volume of fresh water storage and indicates the degree of water available for evapotranspiration.

Exploitable water: indicates water being present in different sources including groundwater, rivers, lakes and reservoirs.

Available water: indicates the amount of water that is available for use at the basin. In fact, it is obtained from the exploitable water minus reserved and non-utilizable outflows.

Protected land use: is the natural ecosystem and environmentally sensitive land use, including shrub land, forests, glaciers, wetlands, natural grasslands as well as protection from sea.

Utilized land use: indicates a low to moderate resource utilization, such as savannah, woodland and mixed pastures.

Modified land use: is the principal vegetation that is replaced for increased utilization of land resources.

Incremental evapotranspiration: the water consumption that is just related to water withdrawals.

Outflows: the amount of water that leaves the basin through surface and subsurface systems including surface and subsurface outflows

References

Abbaspour, K.C., 2015. SWAT-CUP: SWAT Calibration and Uncertainty Programs – A User Manual. Swiss Federal Institute of Aquatic Science and Technology, Eawag.

Alizadeh, A., Kamali, G.A., 2007. Crops Water Requirements. Asstane Ghodse Razavi Press (Beh Nashr), Mashhad.

Allen, R.G., Willardson, L.S., Frederiksen, H., 1997. Water use definitions and their use for assessing the impacts of water conservation. Sustainable Irrigation in Aeas of Water Scarcity and Drought 72–81.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development 1. JAWRA J. Am. Water Resour. Assoc. 34 (1), 73–89.

Arumí, J.L., Rivera, D., Holzapfel, E., Boochs, P., Billib, M., Fernald, A., 2009. Effect of the irrigation canal network on surface and groundwater interactions in the lower valley of the Cachapoal river. Chile Chilean J. Agric. Res. 69 (1), 12–20.

Batchelor, C., Hoogeveen, J., Faurès, J.M., Peiser, L., 2016. Water accounting and auditing. A sourcebook. FAO Water Reports (FAO) eng no. 43.

Chalmers, K., Godfrey, J., Potter, B., 2012. Discipline-informed approaches to water accounting. Aust. Account. Rev. 22 (3), 275–285.

Dechmi, F., Burguete, J., Skhiri, A., 2012. SWAT application in intensive irrigation systems: Model modification, calibration and validation. J. Hydrol. 470, 227–238.

Dor, N., Syafalni, S., Abustan, I., Rahman, M.T.A., Nazri, M.A.A., Mostafa, R., Mejus, L., 2011. Verification of surface-groundwater connectivity in an irrigation canal using geophysical, water balance and stable isotope approaches. Water Resour. Manage. 25 (11), 2837.

FAO Water Reports No, 38, 2012. Coping with water scarcity: An action framework for agriculture and food security.

Farokhnia, A., 2016. Asessment of Land Use Change and Trend in Climate Variables in Tashk-Bakhtegan Basin, Technical report, Iranian Ministry of Energy (in Persian).

Foster, S., Perry, C., Hirata, R., Garduno, H., 2009. Groundwater resource accounting: critical for effective management in a “changing world”. GW-MATE Case Profile 16.

González, J., 2019. Does water efficiency reduce water consumption? The economy-wide water rebound effect. Water Resour. Manage. 33 (6), 2191–2202.

Gregor, M., 2012. Hydrooffice User Manual version, 2012.

Harrison, P.A., Dunford, R.W., Holman, I.P., Holman, G., Madsen, M.S., Sandars, D., 2019. Differences between low-end and high-end climate change impacts in Europe across multiple sectors. Reg. Environ. Change 19 (3), 695–709.

Jägermeyr, J., Gerten, D., Heinke, J., Schaphoff, S., Kummu, M., Lucht, W., 2015. Water savings potentials of irrigation systems: global simulation of processes and linkages. Hydrol. Earth Syst. Sci. 19, 3073–3091.

Jha, M.K., Gassman, P.W., Panagopoulos, Y., 2015. Regional changes in nitrate loadings in the Upper Mississippi River Basin under predicted mid-century climate. Reg. Environ. Change 15 (3), 449–460.

Johnson, W.C., Werner, B., Guntenspergen, G.R., Voldseth, R.A., Millett, B., Naugle, D.E., Tulbure, M., Carroll, R.W., Tracy, J., Olawsky, C., 2010. Prairie wetland complexes as landscape functional units in a changing climate. Bioscience 60 (2), 128–140.

Karimi, P., Bastiaanssen, W.G.M., 2014. Spatial evapotranspiration, rainfall and land use data in water accounting–Part 1: Review of the accuracy of the remote sensing data. Hydrol. Earth Syst. Sci. Discuss 11, 1073–1123.

Karimi, P., Bastiaanssen, W.G., Molden, D., 2013a. Water Accounting Plus (WA+)–a water accounting procedure for complex river basins based on satellite measurements. Hydrol. Earth Syst. Sci. 17 (7), 2459–2472.

Karimi, P., Bastiaanssen, W.G., Molden, D., Cheema, M.J.M., 2013b. Basin-wide water accounting based on remote sensing data: an application for the Indus Basin. Hydrol. Earth Syst. Sci. 17 (7), 2473–2486.

Keller, A.A., Keller, J., 1995. Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources. Center for Economic Policy Studies, Winrock International, Arlington, VA, USA, pp. 1–19.

Kienzle, S.W., Schmidt, J., 2008. Hydrological impacts of irrigated agriculture in the Manuherikia catchment, Otago, New Zealand. J. Hydrol. (New Zealand) 47 (2), 67–84.

Kim, N.W., Chung, I.M., Won, Y.S., Arnold, J.G., 2008. Development and application of the integrated SWAT–MODFLOW model. J. Hydrol. 356 (1–2), 1–16.

Krysanova, V., Srinivasan, R., 2015. Assessment of climate and land use change impacts with SWAT. Reg Environ Change 15, 431–434.

Lankford, B., 2006. Localising irrigation efficiency. Irrigation and Drainage: J. Int. Commission Irrigation Drainage 55 (4), 345–362.

Lankford, B., 2012. Fictions, fractions, factorials and fractures; on the framing of irrigation efficiency. Agric. Water Manag. 108, 27–38.

MOE (Ministry of Energy), 2017, Climate change adaptation strategies and national plans in Water Sector, Simulating water resources and agricultural systems in Tashk-Bakhtegan basin (in Persian).

Molden, 1997. *Accounting for water use and productivity*. 42 IWMI.

Nasri, B., Dadmehr, R., Fouché, O., 2015. Water table rising consecutive to surface irrigation in alluvial aquifers: predective use of numerical modelling. Eng. Geol. Soc. Territory, Springer, Cham 3, 379–382.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2009. 1.1 Overview of Soil and Water Assessment Tool (SWAT) Model. Tier B (All countries/territories not listed here are in Tier A), 8 (3).

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. and King, K.W., 2002. Soil and water assessment tool (SWAT): theoretical documentation, version 2000. Texas water resources institute, college station, TX, TWRI Report TR-191.

Perry, C., 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrigation Drainage: J. Int. Commission Irrigation Drainage 56 (4), 367–378.

Perry, C., 2012. Accounting for water: stocks, flows, and values,“ in UNU-IHDP and UNEP, Inclusive Wealth Report 2012: Measuring Progress toward Sustainability. Cambridge University Press, Cambridge.

Perry, C., Steduto, P., Karajeh, F., 2017. Does Improved Irrigation Technology Save Water? A Review of the Evidence. Food and Agriculture Organization of the United Nations, Cairo, pp. 42.

Perry, C., Steduto, P., Allen, R.G., Burt, C.M., 2009. Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. Agric. Water Manag. 96 (11), 1517–1524.

Raeisi, L.G., Morid, S., Delavar, M., Srinivasan, R., 2019. Effect and side-effect assessment of different agricultural water saving measures in an integrated framework. Agric. Water Manag. 223 105685.

Ramos, M.C., Martínez-Casasnovas, J.A., 2015. Soil water content, runoff and soil loss prediction in a small ungauged agricultural basin in the Mediterranean region using the Soil and Water Assessment Tool. J. Agric. Sci. 153 (3), 481–496.

Rodgers, K., Schlunegger, S., Hales, B., Slater, R., Timmermann, A., 2019. Trend emergence and extreme events in marine ecosystem stressors under 21st century climate change. Geophys. Res. Abstr. 21.

Seaber, P.R., Kapinos, F.P., Knapp, G.L., 1987. Hydrologic Unit Maps: US Geological Survey Water-Supply Paper 2294 (USGS, Reston, VA).

Seckler, D.W., 1996. The new era of water resources management: from“ dry” to“ wet” water savings, Iwmi, 1.

Tibebe, D., Bewket, W., 2011. Surface runoff and soil erosion estimation using the SWAT model in the Keleta watershed, Ethiopia. Land Degrad. Dev. 22 (6), 551–564.

Vazquez-Amábile, G.G., Engel, B.A., 2005. Use of SWAT to compute groundwater table depth and streamflow in the Muscatatuck River watershed. Trans. ASAE 48 (3), 991–1003.

Willardson, L.S., Allen, R.G., Frederiksen, H.D., 1994. October. Elimination of irrigation efficiencies. In Acta 13th Tech. Conf. USCID. Denver, CO, EEUU, pp. 19–22.

Zaman, M.R., Morid, S., Delavar, M., 2016. Evaluating climate adaptation strategies on agricultural production in the Siminehrud catchment and inflow into Lake Urmia, Iran using SWAT within an OECD framework. Agric. Syst. 147, 98–110.