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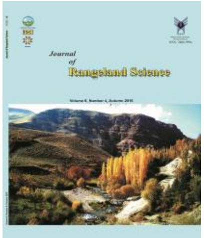

Research and Full Length Article:

Using SWAT Model to Investigate the Impact of Rangeland Management Practices on Water Conservation (Case Study: Gorganroud Watershed, Golestan, Iran)

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Abstract. Hydrological response of a watershed is a comprehensive symbol of environmental conditions and characteristics of the basin. Vegetation is one of the main factors in water resources status, erosion, and sediment of a watershed. Rangelands of Golestan province, Iran due to the geographical location, climate, and destruction of these resources as well as drastic land use changes from forests, and rangelands to agricultural lands have a high potential of run-off. Therefore, in the present study in order to determine the best management of the rangelands, we developed a rangeland improvement model using the Soil and Water Assessment Tool (SWAT) in the Gorganroud Watershed, Golestan, Iran. Calibration and validation of model were performed using Sequential Uncertainty Fitting Program (SUFI-2) in the eco-hydrological model of SWAT. Simulating the run-off in the studied hydrometric stations, the results showed that this model performed well for the study area (P-factor 0.6-0.9; R-factor 0.85-1.5). As well, four range improvement scenarios (mechanical, biological, biomechanical and livestock grazing management) were defined in this study. On average, by applying mechanical, biological, biomechanical, and grazing management scenarios, runoff was reduced to 13.5%, 11%, 20.7% and 12.5%, respectively in comparison with the actual runoff. According to the obtained results, the biomechanical scenario was identified as the best one in reducing the runoff and water conserve in poor and moderate rangelands.

Key words: Rangeland improvement operations, SUFI-2, Biomechanical scenario, Grazing management, Gorganroud watershed

Introduction

Hydrological response of a watershed is a comprehensive symbol of environmental conditions and characteristics of the basin. In a natural ecosystem, land use and changes in environmental conditions especially vegetation affect the hydrological responses such as the amount of run-off and floods in a region. Vegetation is one of the main factors in water resources status, erosion, and sediment of a watershed. Results of researches showed that the implementation of range improvement operations has an important role in controlling surface runoff in watersheds and water conserve in rangeland. In this regard, the roles of mechanical operations and watershed management in the formation of run-off and its quantitative changes are effective (Brooks *et al.*, 1991). Simonovic (2002) suggested the integrated use of mechanical and biological operations in order to achieve greater success in flood control operations. Studies in recent years indicated the occurrence of destructive floods in most parts of Iran (MEI, 2013). According to the available information during 1992-2001, the damage of major floods in the country is close to 300-350 million $ (MEI, 2007) which seems that in 2002-2015, the amount of damage is close to 800 million $. For this reason, varieties of activities are being carried out in connection with the prevention of floods in watersheds as well as in rangelands. Because of the variety of ecological conditions, achieving a specified pattern and or providing a specific instruction having a uniform application in all watersheds is not possible. The reliable assessment of river flow characteristics is basic for the development of water resources (Barkhordari and Semsar Yazdi, 2015). Therefore, in addition to knowing the watershed and its problems, prioritizing range improvement operations and vegetation management proportional to the available potentials is inevitable. In general, the implementation of range improvement operations and vegetation management in the watersheds has an important role in controlling surface run-off. Golestan province is located in the north of Iran. Unfortunately, in this province, the conditions necessary for the formation of run-off are available due to geographical location, climate, the degradation of resources heavy precipitation and geological formations susceptible to erosion as well as a drastic change in land use from rangelands and forests to rain fed lands (Zarghami *et al.*, 2011). The Gorganroud Watershed is one of the most important and strategic watersheds covering about half of the area of Golestan province. The physical conditions of the Gorganroud watershed in this province such as mountainous and steep areas as well as poor land management including conversion of rangelands to rain fed lands at a very broad level together with plowing on slopes and forest clear cuts have led to the increased run-off, soil degradation, and loss of soil fertility. Therefore, it seems that run-off estimation and management practices are essential in order to reduce run-off in this watershed.

SWAT is a semi-distributed model provided by the US Agricultural Research Service to predict the effects of different management on flow, sediment, plant production and chemicals balance in watersheds with different soil, land use and management conditions for long periods (Neitsch *et al.*, 2011). In addition, it has been used widely around the world since 2000 as a developed ecohydrological model to simulate environmental, hydrological, and ecological processes under a wide range of management conditions and climate.

Mapfumo *et al.* (2004) in a study with simulating daily soil water under foothills fescue grazing in Canada simulated three areas of heavy grazing, moderate grazing and enclosure to calculate the soil water with SWAT model. The results showed that the spatial pattern of soil water in the enclosure area was more regular as compared to heavy grazing area, and a good evaluation from soil water resources could be performed using this model in watersheds.

Afinowicz *et al.* (2005) compared brush-covered areas with areas of low brush cover at average slopes and shallow soils in Texas. Their results showed that brush cover caused extensive changes in surface runoff, evapotranspiration, and base flow run-off. In a study conducted in Malaysia, the SWAT model was used to simulate and predict a stream flow and simulation results on a monthly time base were calculated to be 0.65 and 0.62 in the calibration and 0.93 and 0.92 in the validation using R^2 efficiency coefficient and Nash-Sutcliffe coefficient, respectively (Alansi *et al.,* 2009). In their study, five scenarios were designed to determine the effects of land use changes on flow rate and the results of scenarios were investigated. Azimi *et al.* (2013) applied the SWAT model to estimate the production of the Hablehrood watershed located in Tehran and Semnan provinces. According to the SWAT model, the changes of simulated production in the semi steppe, steppe and desert areas were calculated to be 0.03-0.05, 0.15-0.26, and 0.033-0.10 tons per hectare, respectively.

According to the literature cited above, the semi-distributed SWAT model is perfect to simulate runoff and erosion as well as simulation of the impact of management factors on runoff in the studied watersheds. Overall in all studies, considering the evaluation criteria, this model showed the efficiency and accuracy needed and could be used to simulate the effects of range management on runoff from the watershed. However, since the SWAT model has been used widely in many countries, testing its parameters in various fields of agriculture and natural resources in the watersheds has been considerable for many users.

The main objectives of this study are i) To make a model river discharge in rangeland, ii) to calibrate discharge from 1984 to 2002 and to validate from 2003 to 2011, and iii) to use the calibrated model for the assessment of rangeland improvement scenarios on water conversation.

Materials and Methods

Study area

Gorganrood River basin is located between 36° 25´ to 38° 15´ Northern latitude and 56° 26´ and 54° 10´ Eastern longitude in Iran and has a drainage area of 11333 km^2, a third of which is rangelands (Fig. 1). This watershed is limited to the Eastern Alborz Mountains, Aladagh and Golidagh Mountains, Atrak watershed, and Caspian Sea and Gharehsou Watershed from the South, East, North, and West, respectively. Alborz northern highlands having an extreme difference with the alluvial plain with high rainfall cause to make South-Northern Rivers with a high erosion power. Upon reaching the plains, these rivers form coarse alluvial fans, deposit their main sediment, and then enter to the old river called Gorganroud. The altitude range is between 132 to 2133 m with the mean annual rainfall of 496 mm and mean temperature of 17.8°C. Figure1 shows the location of Gorganroud watershed in the country and province. The vegetation map and rangeland condition of Gorganroud watershed are presented in Fig. 2. The mean “Mix” in this map is small and mixed patches include forest, rangeland, agriculture and bare land.

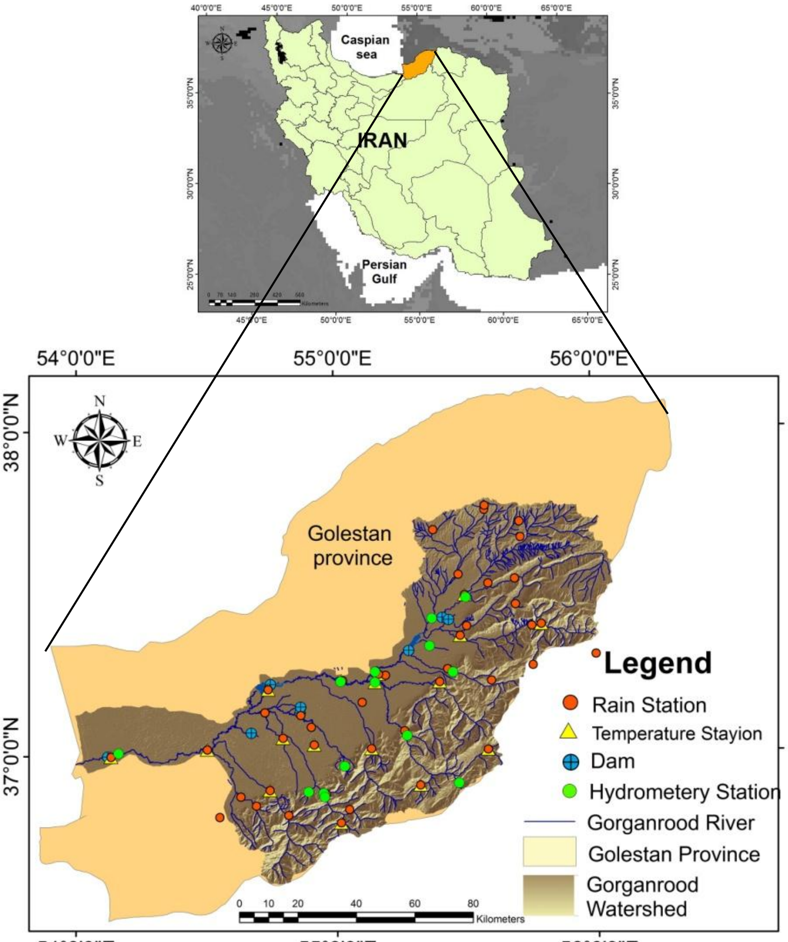

Fig. 1. Location of Gorganroud watershed in the country and province

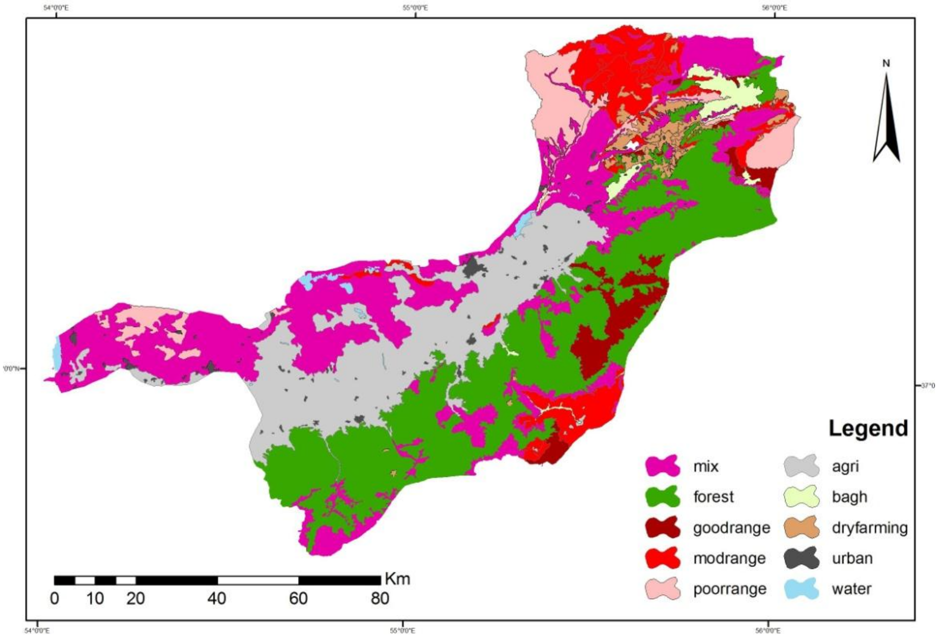

Fig. 2. Land use map and rangeland conditions of Gorganroud watershed

Model Description

SWAT is a comprehensive, physically-based model that was developed to predict the impact of land management practices on water, sediment and forage production in large complex watersheds with varying soils, land uses, and management conditions over long periods. It requires specific information about water, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, plant growth, nutrient cycle, etc are directly modeled by SWAT using these input data (Neitsch *et al.*, 2011).

The plant growth component of SWAT is a simplified version of the EPIC plant growth model. Differences in growth between plant species are defined by the parameters contained in the land use database. Plant growth is simulated by computing leaf area development, light interception and its conversion to biomass and forage production (Neitsch *et al.*, 2011). LAI and root development are simulated using the plant growth component of SWAT. Phenological plant development is based on daily accumulated heat units, potential biomass, and harvest index. Harvest index is the fraction of above-ground dry biomass that is removed as dry economic forage production. Plant growth in the model can be inhibited by temperature, water, nitrogen, and phosphorus stress factors.

Plant communities that have been simulated using SWAT include crops and weeds, trees and grasses, different tree species in a boreal forest, and grasses and shrubs in rangeland communities. Management operations that control the plant growth cycle such as beginning of growing season, harvest, end of growing season, tillage, grazing, fertilizer, irrigation, and pesticide are included in the SWAT (Neitsch *et al.*, 2011).

SWAT model input data and methods

The model input data were collected from different sources as follows:
Digital elevation map from the SRTM Satellite with an accuracy of 30 m (Global NASA/NGA); soil and vegetation map with a scale of 1: 50,000; also soil data including soil texture (sand, silt and clay), organic matter content, pH, EC, lime and organic carbon, soil depth and structure from the Department of Natural Resources and watershed management in Golestan; meteorological data (including daily precipitation, maximum and minimum temperature) from the Meteorological Organization (1981-2011)(WSIMO, 2009); data of hydrometric stations such as monthly discharge during 1981- 2011 from Golestan Regional Water Authority. Eight major reservoirs were built during 1983 and 2009 for hydropower storage for irrigation and drinking water supply, and flow regulation. Information of reservoirs include located reservoirs, reservoir operational year and month, reservoir surface area, reservoir volume of water, sediment concentration and reservoirs monthly out flow. To determine the parameters of rangeland species and rangeland conditions for inclusion in the SWAT land use database, we used historical data. Historical data were obtained for the annual forage production, and the area covered with rangelands and rangeland assessment in Golestan from 2003 to 2008 from Golestan Agricultural and Natural Research Center (Khatir, 2008).

To work with the model, the Digital Elevation model (DEM) of the study area was initially introduced. Then, considering the topographic features, the watershed network was determined and the minimum area for sub-watersheds was calculated to be 500 ha according to the aim of the study and hardware and software constraints. The stream outlet to the Caspian Sea was defined as the watershed outlet to develop the watershed boundary. In next stage, vegetation and soil map were introduced to the model. The model converts these maps to the raster maps with the cells having a size equal to the cell size of digital elevation model. The map of hydrological response units was obtained by combining these three layers. According to the methods considered for estimating the evapotranspiration, the SWAT model needs precipitation and minimum and maximum daily temperature data. These data were prepared in DBF format to be entered to the model. In addition, the coordinates and altitude of the temperature and precipitation stations were developed with this format to be used in the model.

Model calibration and validation

According to the studies conducted, 22 sensitive parameters related to water and soil *(*Faramarzi *et al.,* 2009; Abbaspour *et al.,* 2007; Wang *et al.,* 2005*)* and 23 sensitive parameters related to plant growth and yield (Azimi *et al.,* 2013; Corson *et al.,* 2006; Luo *et al.,* 2008 and Faramarzi *et al.,* 2010) were selected in order to do preliminary assessment. The calibration of quantitative and continuous models such as SWAT is based on the values simulated with the observed ones. Due to the number of SWAT model parameters, optimization algorithm needs to be used for automatic calibration. The genetic algorithm is one of the methods used for SWAT automatic calibration as well as methods in the SWAT-CUP software package prepared by Abbaspour (2011). In this method, the range of model parameters varies systematically to be close to optimal values. The parameters obtained from sensitivity analysis are selected as optimization decision variables and their change ranges are SUFI2 input. The values were selected randomly from the parameter range. Then, the SWAT model was run and the desired output (in this study, runoff of each sub-basin) was extracted from output files. According to the observed and new simulated data, the calibration objective functions of R and P were determined and the forecast uncertainty was evaluated. If the objective function and other calibration standards reach the desired values, calibration is stopped. Otherwise, the obtained optimal parameters are replaced with previous values and the mentioned steps are repeated again. Iterations are continued as far as the objective function as well as R-factor and P-factor have acceptable values according to the user comments. To ensure the accuracy of model, the results of model validation period could be controlled to achieve the optimal answer. In order to compare the discharge simulated and measured data from the objective function, the Nash-Sutcliffe coefficient was used. This is another tool showing the relative difference between the observed and simulated data. The value of this coefficient varies between one and negative infinity. Values between zero and one are acceptable while those less than zero are unacceptable. If its value is greater than 0.5, it indicates that model has a good simulation and if it is negative, it is better to avoid relying on model results and the average of observational values need to be used (Moriasi *et al.,* 2007). According to Geza and Mccray (2008), Nash Sutcliffe values greater than 75% and values between 0.36 and 0.75 were considered excellent and satisfactory, respectively. In the current study, R-factor and P-factor were used for uncertainty analysis.

Results and Discussion

Before performing the calibration, it is necessary to determine sensitive parameters. Sensitivity analysis is necessary since model input parameters are quite high. Therefore, the parameters which model output is more sensitive to need to be identified and applied in the model calibration. Accordingly, the parameters affecting the estimation of river discharge and plant production were determined as well as calculating t-value and p-value presented in Table 1.

In general, in this watershed, we see some parameters sensitive to discharge including (CN2, GWQMN, REVAPMN, SFTMP, SMTMP, SURLAG, ALPHA BNK, EPCO, SOLK, and ESCO) and seven parameters including T_OPT, FRGMAX, WSYF, CNOP, LAIMX1, SOL_AWC and SOL_BD that are sensitive to forage production.

Table 1. Description of SWAT input parameters included in the calibration process and their sensitivity statistics

Parameter	Definition	t-Value[b]	p-Value[c]
Parameters sensitive to discharge			
r CN2.mgt	SCS curve number for soil moisture condition	21.03	0.00
v GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	18.11	0.00
v REVAPMN.gw	Capillary rise shallow aquifer to root zone coefficient (–)	15.25	0.00
v SFTMP.bsn	Snowfall temperature (◦C)	14.77	0.00
v SMTMP.bsn	Snow melt base temperature (◦C)	9.51	0.00
v SURLAG.bsn	Surface runoff lag time	8.24	0.00
v ALPHA BNK.gw	Base flow alpha factor for bank storage (days)	2.47	0.01
v EPCO.hru	Plant uptake compensation factor	1.93	0.02
r SOLK.sol	Soil saturated hydraulic conductivity (mm h^{-1})	1.71	0.02
v ESCO.hru	Soil evaporation compensation factor	1.24	0.03
r SOL BD.sol	Soil bulk density (g cm^{-3})	0.98	0.21
r SOL AWC.sol	Soil available water storage capacity (mm H2O/mm soil)	0.79	0.20
v CHK2.rte	Effective hyd. cond. in the main channel	0.33	0.53
v SMFMN.bsn	Minimum melt rate for snow during years (mm c day^{-1})	0.25	0.52
v SMFMX.bsn	Melt factor for snow on June 21	0.18	0.39
v ALPHABF.gw	Base flow alpha factor (days)	0.08	0.88
Parameters sensitive to forage production			
v T_OPT.CROP	Optimal temperature for plant growth (c)	11.48	0.00
v FRGMAX.CROP	Fraction of maximum stomatal conductance…	8.25	0.00
v WSYF.CROP	Lower limit of harvest index	6.84	0.00
r CNOP.mgt	SCS run off curve number for moisture conditionII	4.21	0.00
v LAIMX1.CROP	Fraction of the maximum leaf area index	6.94	0.00
r SOL_AWC.sol	Soil available water storage capacity (mm H2O/mm soil)	7.01	0.00
r SOL_BD.sol	Soil bulk density (g cm−3)	3.21	0.00
v BIO_EAT.mgt	Dry weight of biomass consumed daily(kg/ha/day)	0.90	0.31
v BIO_MIN.mgt	Min plant biomass for grazing(kg/ha)	0.11	0.11
r CN2.mgt	SCS runoff curve number	0.05	0.81

v=parameter value is substituted by a value from the given range;
r=parameter value is multiplied by (1 + a given value) (Abbaspour *et al.,* 2007)

Run-off Calibration and Validation

After sensitivity analysis, runoff calibration for the period of 1984-2002 was done using flow monthly data. Calibration statistics for the Basir Abad discharge station (Table 2) indicates the bracketing of more than 60% (P-factor ranges from 0.6 to 0.9) of the observed data within the 95PPU band (Fig. 3). The R-factor ranges from 0.62 to 2.5. The overall calibration results are quite satisfactory although at Node, Kabod Vall, and Tilab Abad stations, the uncertainty is larger than the other stations. This could be due to high level of water and land management as well as other water sources such as springs, which were not accounted for in the model due to lack of data. This problem is also considered in other studies such as the one done by Azimi *et al.* (2013). The validation results have in general smaller prediction uncertainties as indicated by smaller R-factors. This could be due to fewer years of data allocated to validation. Although the calibration period covers a period of 19 years, quite few data points existed in some stations.

Table 2. Discharge calibration and validation results at 13 hydrometric stations

Hydrometric station	Rangeland condition	Calibration (1984–2002)		Validation (2003–2011)	
		P-factor	*R-factor*	*P-factor*	*R-factor*
Tamer	Poor	0.81	1.32	0.65	1.52
Haji Ghoshan	Moderate-Poor	0.68	1.32	0.68	1.63
Gonbad	Moderate-Poor	0.61	0.84	0.67	0.68
Araz Kose	Moderate	0.54	0.63	0.54	0.64
Ghazaghli	Moderate-Poor	0.69	1.55	0.81	0.54
Shir Abad	-	0.77	0.62	0.75	0.49
Basir Abad	Poor	0.88	1.52	0.69	1.02
Kabod Vall	Moderate	0.68	1.93	0.61	1.86
Node	Moderate	0.64	2.58	0.71	1.03
Til Abad	Good	0.58	1.66	0.62	1.86
Sorme Rood	-	0.61	0.32	0.62	0.35
Zaringol	-	0.73	0.80	0.73	0.81
Gali kesh	Moderate-Good	0.64	0.70	0.72	0.49

Figs. 3 and 4 show the results of discharge calibration and validation for the study of Basir Abad station as an example.

As it can be deduced from Figs. 3 and 4, calibration and validation results show that SWAT model can be a useful tool in relation to discharge simulation. Abbaspour *et al.* (2007), Gassman *et al.* (2007), Faramarzi *et al.* (2010) and Azimi *et al.* (2013) also emphasized the ability of SWAT model simulation.

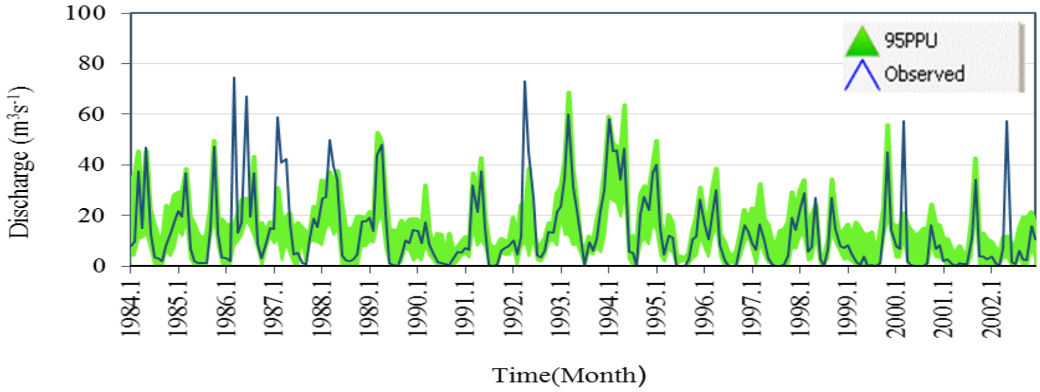

Fig. 3. Results of calibration comparison between discharge observational and simulated data (confidence band 95%) for different months in each year

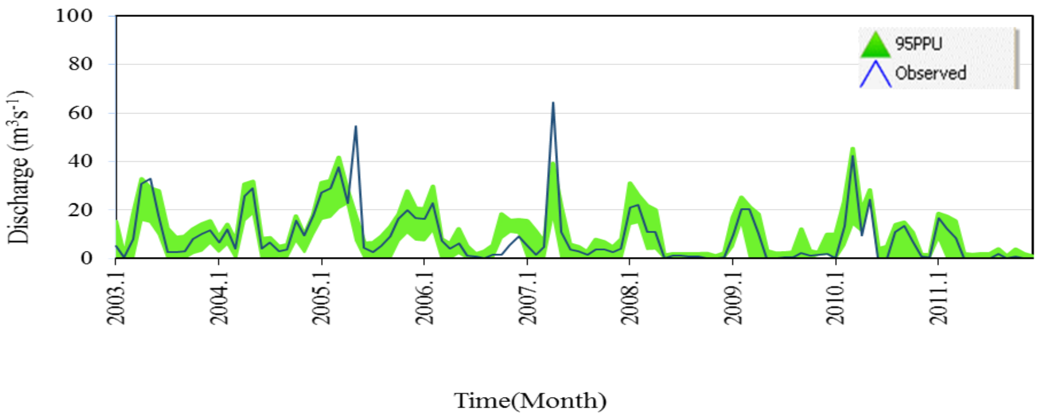

Fig. 4. Results of validation comparison between discharge observational and simulated data (confidence band 95%) for different months in each year

Assessment of range management scenarios using simulated models

After ensuring model capability in watershed runoff simulation, four rangeland improvement scenarios including mechanical, biological, biomechanical and livestock grazing management were introduced to the model and runoff variations were investigated. Table 3 shows the results of runoff based on range conditions under management scenarios. As it can be seen, the amount of runoff is reduced by applying any of the management scenarios. On average, by applying mechanical, biological, biomechanical, and grazing management scenarios, runoff was reduced to 13.5%, 11%, 20.7% and 12.5%, respectively in comparison with the actual runoff (Control). Biomechanical operations had the greatest impact. Nowadays, the importance of the study of runoff is obvious. Moreover, there is a growing demand to more complete and more detailed information of watersheds in order to manage them; therefore, due to time and especially financial constraints, field visits could not be enough to make rational decisions and cannot cover the whole area. In this regard, simulation models have consolidated their position greatly.

Table 3. Results of runoff under management scenarios

Rangeland condition	Control	The percentage of runoff decrease for each scenarios			
	The average runoff (mm/years)	Mechanical operation (mm/years)	Biological operation (mm/years)	Biomechanical operation (mm/years)	Grazing management (mm/years)
Poor	27.86	14.35%	7.32%	19.23%	9.65%
Poor- Moderate	37.35	17.80%	11.24%	25.50%	7.7%
Moderate	19.76	8.4%	13.6%	17.6%	16.5%
Good	17.23	-	-	-	16.4%

Conclusion

The SWAT model has been designed and used by multiple users since 1998. This model could have a good position in runoff and water quality studies and soil and water management and conservation as well as crop yield so that it has been used in watersheds with different conditions, areas, land uses, and climates. According to the result of this research, it seems that the SWAT model provides better results in watersheds with larger area and longer statistical periods as well as monthly time steps. In this study, the SWAT model was applied to predict the effects of range management scenarios on the runoff of Gorganroud watershed. After calibration, this model could have a satisfactory prediction of watershed discharge with SUFI-2 algorithm. The SWAT model could show the effects of range management scenarios on runoff. Comparison of real and simulated discharge with SWAT model during calibration and validation period shows that this model simulates the base flow more accurately in the beginning of warm months. According to the obtained results, the biomechanical scenario was identified as the best one in reducing the runoff and water conserve in poor and moderate rangelands.

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کاربرد مدل سوات به منظور تشخیص اثرات مدیریت مرتع بر روی حفظ آب (مطالعه موردی: حوزه آبخیز گرگانرود، گلستان، ایران)

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چکیده. واکنش هیدرولوژی یک حوزه آبخیز، نماد جامعی از شرایط و خصوصیات محیط طبیعی آن حوضه می‌باشد. پوشش گیاهی یکی از عوامل اصلی در وضعیت منابع آب، فرسایش و رسوب یک حوزه آبخیز می‌باشد. مراتع استان گلستان به علت موقعیت جغرافیایی، اقلیمی و تخریب بالای این منابع همچنین تغییر شدید کاربری اراضی از مرتع و جنگل به اراضی زراعی شرایط لازم برای تشکیل رواناب را دارد. بنابراین به منظور تعیین چگونگی مدیریت بهینه این مراتع در این تحقیق مدل پیش‌بینی تولید رواناب مرتع با استفاده از مدل SWAT در حوزه آبخیز گرگانرود مورد بررسی و ارزیابی قرار گرفت. واسنجی و اعتبارسنجی مدل توسط برنامه SUFI-2 در مدل اکوهیدرولوژیکی SWAT انجام گرفت. نتایج نشان داد، این مدل به خوبی برای منطقه اجرا شده و رواناب را در ایستگاههای هیدرومتری مورد مطالعه خوب شبیه سازی کرده است (Pfactor: 0.6-0.9; R-factor: 0.85-1.5). همچنین چهار سناریوی اصلاحی مرتع (بیو مکانیکی، بیولوژی، مکانیکی و مدیریت چرای دام) در این تحقیق تعریف گردید. بر این اساس با کاربرد سناریوهای مکانیکی، بیولوژیکی، بیومکانیکی و مدیریت چرا مقدار رواناب به ترتیب ۱۳/۵٪، ۱۱٪، ۲۰/۷٪ و ۱۲/۵٪ در هر سناریو نسبت به میزان رواناب واقعی کاهش پیدا کرده است. نتایج نشان داد که سناریوی بیومکانیکی مناسب‌ترین سناریو در کاهش میزان رواناب در مراتع ضعیف و متوسط می‌باشد.

کلمات کلیدی: عملیات اصلاحی مرتع، برنامه SUFI-2، سناریو بیومکانیکی، مدیریت چرا، حوزه آبخیز گرگانرود