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Using SWAT Model to Determine Runoff, Sediment Yield and Nitrate Loss in Gorganrood Watershed, Iran

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ABSTRACT The adequacy of the SWAT model in the estimation of runoff, sediment yield and nitrate loss in the Gorganrood watershed was tested, using the existing spatial database as the primary data. The model was then executed for a 31-years' time period. In combination with the SWAT model, the Sequential Uncertainty Fitting Program (SWAT-CUP and SUFI-2) was added used to calibrate and validate a hydrologic model of the watershed. The obtained values at 14 stations were between 0.48 to 0.83 for NS and 0.58 to 0.90 for R^2, respectively. The results showed that nitrate loss was higher in cultivated lands, and in the loess deposits. The maximum amounts of runoff and sediment yield were largely produced in steep areas of the watershed, where dry farming was practiced. In general, the results showed that SWAT could be a proper tool for simulating runoff, sediment yield and nitrate loss into the river.

Key words: *SWAT model, SUFI-2, Runoff, Sediment, Nitrate loss*

1 INTRODUCTION

Soil is an important component of terrestrial ecosystems because it preserves nutrient reserves and supports many biological processes (Kooch *et al*., 2015).Soil erosion is one of the most important environmental issues affecting agriculture and food production that is intensified by increasing human activity (Bayramin *et al.*, 2003). Erosion leads to the loss of organic matter and inorganic components that are responsible for many of the soil's physical properties since they play a central role in the development and stability of a soil (Milne and Haynes, 2004). Surface runoff can translocate very large amounts of nutrients in a solution in water and in sediment (Lowrance and Williams, 1988). Nitrogen (N) is one of the important soil nutrients affecting crop growth. Intensive agriculture has led to environmental degradation through soil erosion and associated nitrogen losses from agricultural land to stream networks (Sharma and Rai, 2004). Excessive application of N fertilizer can result in a build-up of soil N and may reduce

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water quality (Conan *et al*., 2002). Modelling is a way to estimate soil erosion and sediment yield to investigate nutrient losses. There might be a question as "why the hydrological processes of precipitation, runoff and sediment yield have to be modeled", for which there are many answers. The main answer is that appropriate measurement methods in hydrology are limited. Modeling is, therefore, an effective way to develop the required knowledge regarding the hydrological changes and their consequences in future (Beven and Freer, 2001).

The Soil and Water Assessment Tool (SWAT) (Arnold *et al*., 1998) was used to build a coupled hydrology-nitrate loss model for the Gorganrood River Basin in northern Iran. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. This model has the capability of being connected to GIS software (Neitsch*et al*., 2011). It is a physically based, continuous time and watershed scale model.

Physical and process-based models are useful to understand the complex relations and interactions of the components influencing the sustainability of natural ecosystems (Azimi *et al*., 2013). Golestan province has high rates of soil erosion due to geographical location, climate, the destruction of natural resources and highly susceptible loess sediments. Covering about half of the Golestan province, Gorganrood watershed is an important and strategic watershed. This watershed is an agricultural area and plays a valuable role in Golestan province's economy. Despite the large outlets of the river basin, flooding is considered an important issue in the region every year. Although many studies have been done in this area, integrated studies on the hydrological process simulation are scarce. In this work we used the SWAT model to predict sediment yield and nitrate loss in Gorganrood watershed. It is also widely used to simulate the ecological, hydrological, and environmental processes under a range of climatic and management conditions throughout the world (Gassman *et al*., 2007). The main objectives of this study are therefore to: (i) evaluate the performance of SWAT for simulating runoff, sediment and nitrate loss in Gorganrood watershed; (ii) illustrate and discuss the problems associated with model parameterization and (iii) analyzing the impact of parameter uncertainty on model output and ability.

2 MATERIALS AND METHODS

2.1 Description of the study area

Located in Golestan province in Northern Iran (36 °25´ to 38 °15´ N and 56 °26´ to 54 °10´ East),the watershed of Gorganrood covers a drainage area of about11330 $km^2$with a major river –Gorganrood (Figure 1).The major part of the study area is covered with mountains and hills with the parent materials mainly composed of loess deposits. The main plant species of the forest land are *Alanus subcordata*, *Parrotia persica*, *Carpinus betulus* and *Crataegus* sp. The farmlands are mainly under wheat cultivation. Mean elevation and mean slope of the watershed are about 619 m, and 18%, respectively. The lowest and the highest points areBasirabad gauging station (-12 m above sea level) and Shahkooh station (3113m above sea level), respectively. Rainfall variability in the form of torrential and conventional episodes is quite remarkable (Ziyaee *et al*., 2012). The annual rainfall is approximately 287 mm in Robat Gharebil station and about 880 mm at Pasposhte station and annual mean temperatures are between 11 and 18 °C (Golestan Regional Water Corporation, 2011).

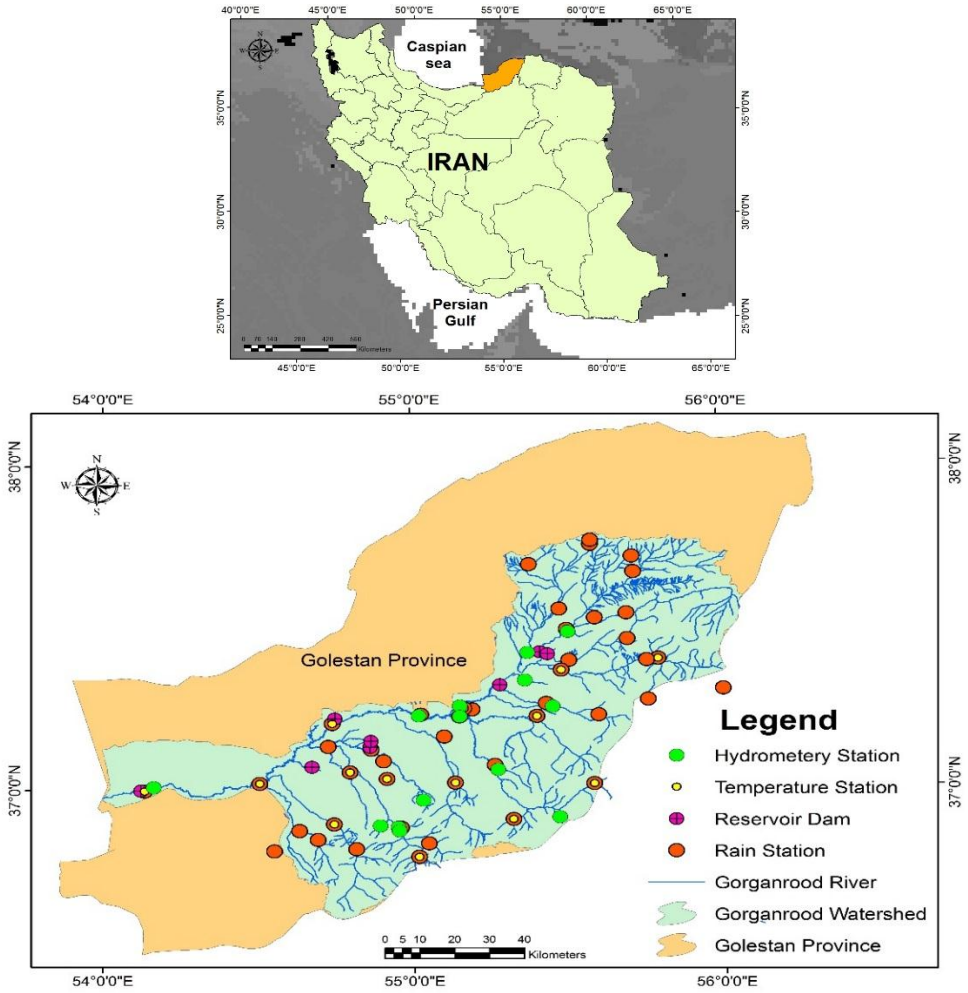

Figure 1 Location of Gorganrood watershed with river network and meteorological stations in Golestan province

2.2 Model description and input

Being a comprehensive and physically-based model, SWAT was developed to predict the impact of land management practices on water, sediment and forage production in large complex watersheds with varying soils, land use, and management conditions over long periods of time. 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 model is based on the water balance general equation:

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

Where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day *i* (mm H_2O), *t* is the time (days), R_{day} is the amount of precipitation on day *i* (mm H_2O), Q_{surf} is the amount of surface runoff on day *i* (mm H_2O), E_a is the amount of evapotranspiration on day *i* (mm H_2O), W_{seep} is

the amount of water entering the vadosezone from the soil profile on day i (mm H_2O),and Q_{gw} is the amount of return flow on day *i* (mm H_2O) (Neitsch *et al*., 2011).To calculate the surface runoff, the SCS curve number procedure was used. This method calculates the surface runoff based on soil type, slope, initial soil moisture state, land use, and management practices (Arnold *et al*., 1995).The Hargreaves method was used to calculate potential evapotranspiration. This method only needs daily values for minimum and maximum temperatures and geographical location. Detailed descriptions of the methods used in modeling these components and subcomponents canbe found in Arnold *et al*. (1998) and Neitsch *et al* (2011).

2.2.1 Map

Data required for this study were compiled from different sources. Digital elevation map from the SRTM Satellite with an accuracy of 30 meters (Global NASA/NGA) (Figure 2A); texture of topsoil(Figure 2B) and land use/cover map with a scale of 1:50,000 from the Golestan Department of Natural Resources and Gorgan University of Agricultural Sciences and Natural Resources(Figure 2C).; soil data including soil texture (sand, silt and clay), organic matter content, soil acidity, EC, soil depth and structure. All of the above information has been presented in a SWAT model format.

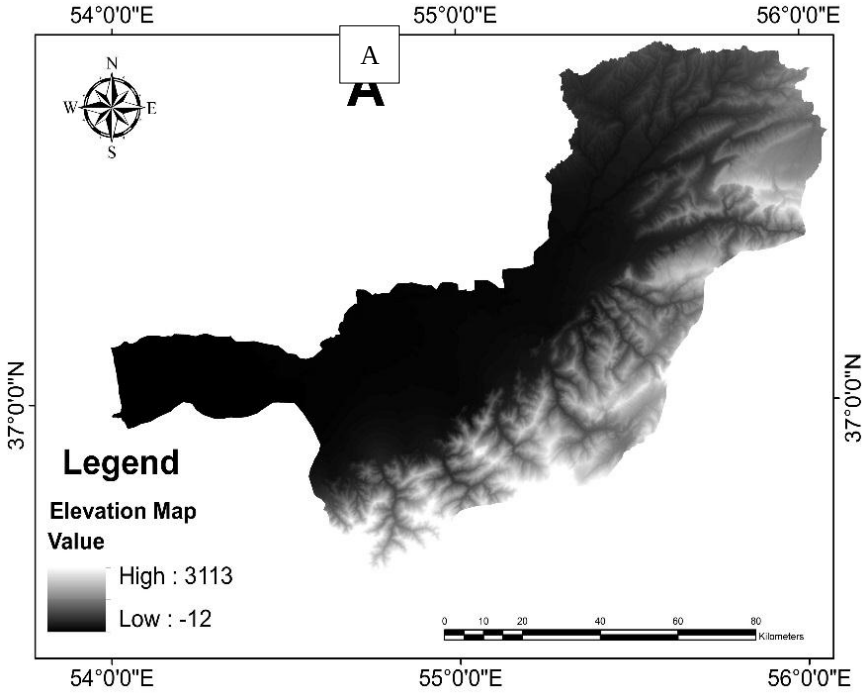

Figure 2 (A) Digital Elevation Model (DEM); (B) land use map (C) texture of topsoil map

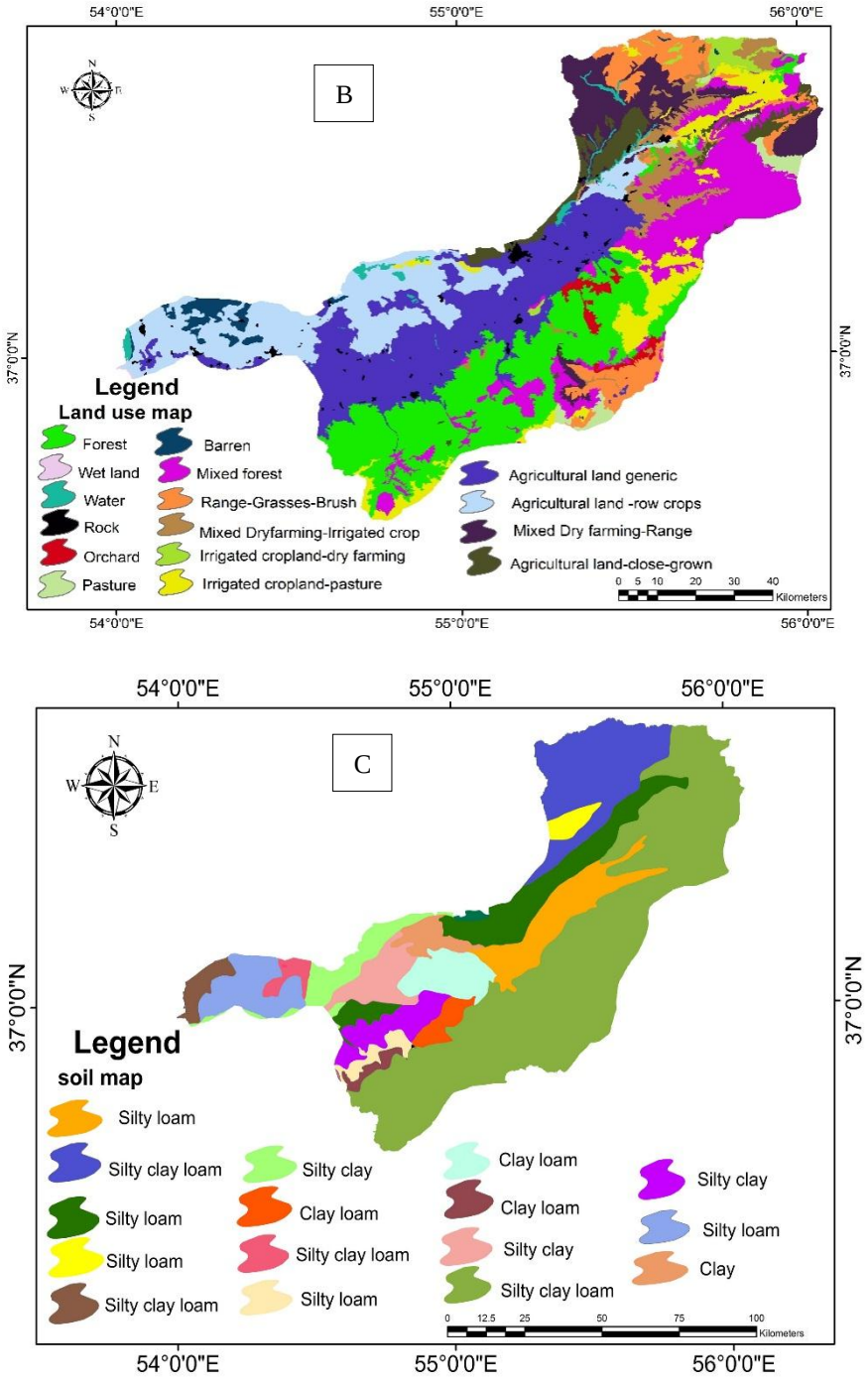

Figure 2 Continued

2.2.2 Reservoirs

Eight major reservoirs were built during the years 1983-2009 for water flow regulation, hydropower, and storage for irrigation and drinking supply. Information of these reservoirs includes location (Figure 1), surface area, volume, operational year and month, sediment concentration and reservoirs monthly out flow.

2.2.3 Climate data

Weather input data (daily precipitation, maximum and minimum temperature, daily solar radiation), were obtained from Public Weather Service of the Iranian Meteorological Organization (WSIMO) for 45 rainfall gauges and 16 temperature recording stations in and around the watershed.

2.2.4 River Discharge and Sediment Data

The measurement data for the water flow and suspended sediment during the years 1981-2011 (Golestan Water Organization reports) were collected. These data were from fourteen main hydrometric stations in the proximity to the main outlet of the basin.

Temperature and rainfall data for 31 years (1981-2011) were collected from the Golestan Meteorological Organization reports and analyzed to determine various statistical parameters (mean, standard deviation, skewness etc.) for mean monthly and annual rainfall and temperature.

After preparing the required data files and information layers, the SWAT model was run from 1981 to 2011. The Sequential Uncertainty Fitting Program SUFI-2 (Abbaspour *et al*., 2007) was used for calibration and uncertainty analysis.

3 RESULTS AND DISCUSSION

3.1 Model calibration and validation

Model calibration and validation was based on river discharge and sediment data from 14 hydrometric stations and nitrate data from 4 gauging stations. The simulation periods for calibration and validation were carried out monthly using discharge and sediment data for the hydrological years from January 1981 to March 2011; the first 3 years (1981-1983) were used as warm-up period to mitigate the unknown initial conditions and were excluded from the analysis (e.g., soil moisture, groundwater level, ground residue, nutrient pool, etc.,).

3.2 Sensitivity analysis

Following previous studies (Faramarzi *et al*., 2009; Azimi *et al*., 2013), 34 aggregate SWAT parameters related to discharge, sediment and nitrate losses at the watershed outlet were selected. The calibration process begun by 50 parameters in the SUFI-2 algorithm, but in the last iteration only 24 were found to be sensitive to discharge, sediment and nitrate losses, because high correlated parameters with the smallest sensitivities were not changed any longer in the iteration process. The calibration parameters are presented in Table 1. The t-value provides a measure of sensitivity (larger values are more sensitive) andp-values determine the significance of thep-value (the smaller, themore significant) (Abbaspour, 2007).

After identifying thesensitive parameters, model simulations were performed in 500 steps and a total of over 10 million visits were conducted for the period and at each iteration, range of the parameters were adjusted. Discharge and sediment calibration were based on monthly simulations. The final values of the parameters for discharge, suspended sediment and nitrate that have been adjusted in the calibration process are illustrated in Table 2. In this table, range of each parameter were reported for the whole watershed, and not for each of the170 parameters, which are differentiated based on different soils, land uses, and watershed. Parameterization of the model to achieve good simulations of monthly flow and sediment yield for long hydrological periods and different rainfall (climate), slope, soil and land use is necessary.

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

Parameter	Definition	t-Value	p-Value
Parameter 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
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 H2Omm $soil^{-1}$)	0.79	0.20
v CHK2.rte	Effective hydraulic conductivity in the main channel(mm h^{-1})	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	0.69
v ALPHABF.gw	Base flow alpha factor (days)	0.08	0.88
Parameter sensitive to sediment			
v PRF.bsn	Peak rate adjustment factor for sediment routing	16.55	0.00
v SPCON.bsn	Linear parameters for calculating the channel sediment rooting	10.11	0.00
v SPEXP.bsn	Exponent parameter for calculating the channel sediment routing	5.90	0.00
v CH_EROD.rte	Channel erodibility factor	1.20	0.17
v CH_COV.rte	Channel cover factor	0.90	0.30
Parameter sensitive to nitrate			
v CDN.bsn	De nitrification exponential rate coefficient	14.48	0.00
v SDNCO.bsn	De nitrification threshold water content	12.25	0.00
v FRTSURFACE.mgt	Fraction of fertilizer applied to top 10 mm of soil	11.84	0.00
v NUPDIS.bsn	Nitrogen uptake distribution parameter	8.21	0.00
v SHALLSTN.gw	Initial NO3concentration in shallow aquifer (mg NL^{-1})	7.94	0.00
v NPERCO.bsn	Nitrogen percolation coefficient	7.01	0.00
v RCN.bsn	Concentration of nitrogen in rainfall (mg NL^{-1})	3.21	0.00
v ERORGN.hru	Organic N enrichment ratio	0.90	0.31
v SOLORGN.chm	Initial organic N concentration in the soil layer (mg kg^{-1})	0.10	0.11
v SOLNO3.chm	Initial NO3concentration in the soil layer (mg kg^{-1})	0.05	0.81

Table 2 SWAT model parameters included in the calibration and their initial and final ranges

Parameter	Initial range (variable by sub-basin)	Final parameter range (variable by sub-basin)
Discharge parameters		
r CN2.mgt	[-0.7,0.70]	[-0.4,0.42]
v GWQMN.gw	[10.0,30.0]	[25.0,28.0]
v REVAPMN.gw	[0.0,100]	[7.0,65.0]
v ESCO.hru	[0.01,1.00]	[0.60,0.70]
v SFTMP.bsn	[-0.5,0.5]	[-4.21,-2.61]
v SMFMN.bsn	[0.0,10.0]	[0.21,2.47]
SURLAG.bsn	[0.01,1.00]	[0.245,0.49]
v ALPHA BF.gw	[0.00,1.00]	[0.01,0.19]
v EPCO.hru	[0.01,1.00]	[0.71,0.85]
r SOLK.sol	[-0.50,0.50]	[0.06,0.01]
v ESCO.hru	[0.01,0.90]	[0.062.0.345]
Sediment parameters		
PRF.bsn	[0.00,100]	[0.09,0.15]
SPCON.bsn	[0.0001,0.01]	[0.0003,0.002]
SPEXP.bsn	[1.00,2.00]	[1.09,1.25]
CH_EROD.rte	[0.00,0.60]	[0.20,0.385]
Nitrate parameters		
v CDN.bsn	[0.00,3.00]	[0.01,1.20]
v SDNCO.bsn	[0.00,1.00]	[0.01,0.50]
v FRTSURFACE.mgt	[0.00,1.00]	[0.01,0. 30]
v N-UPDIS.bsn	[0.00,100]	[52.00,58.00]
v SHALLST-N.gw	[0.00,40]	[0.00,1.50]
v NPERCO.bsn	[0.00,1.00]	[0.03,0.41]

3.2.2 Discharge calibration and validation

Since SWAT model has a physical base, simulating the output discharge from sub-basin before simulation of sediments is necessary. After adapting of model to the specific conditions of the study area, simulation of sediments can be done, upon which SWAT outputs were evaluated for goodness of fit using two model performance indicators: the NS coefficient (Nash and Sutcliffe, 1970) and the coefficient of determination (R^2) (Moriasi *et al*., 2007). The NS evaluates the goodness of fit of simulated and measured data and ranges from negative infinity to 1, where the value of 1 indicates perfect model accuracy.

The simulation of the average monthly discharge for the terminal outlet of Gorganrood watershed (Basirabad station) generated good results in comparison with the observed discharge (Figure 3).The performance statistics showed the model was able to represent flow conditions successfully at Basirabad station. The Nash–Sutcliffe coefficient of efficiency for discharge was 0.63 and 0.67 for the calibration and validation periods, respectively.

An inspection of Figure 3 indicates that the model tends to underestimate flow volumes and storm peaks more often in the winter and spring months (e.g. 1983, 1992, 1993, 1994 and 2005). In addition, the flow volumes were frequently overestimated in the summer months (e.g. 1989, 1990, 1999, 2000, 2003 and 2008). Figure 3 shows lower peak in 1986 and 1987 for simulated discharge. Although investigation of rainfall at those periods can confirm it, observational discharge higher discharge peak.

This difference could be due to measurement error in discharge in the hydrometric station or the lack of consideration of using water for agricultural and industrial purposes. Investigation of rainfall in calibration period showed that in February 1990, a rainfall occurred that led to peak discharge, but this peak discharge had not been recorded in the hydrometric station.

A summary of the results for the hydrology calibration at all four flow stations is included in Table 3.

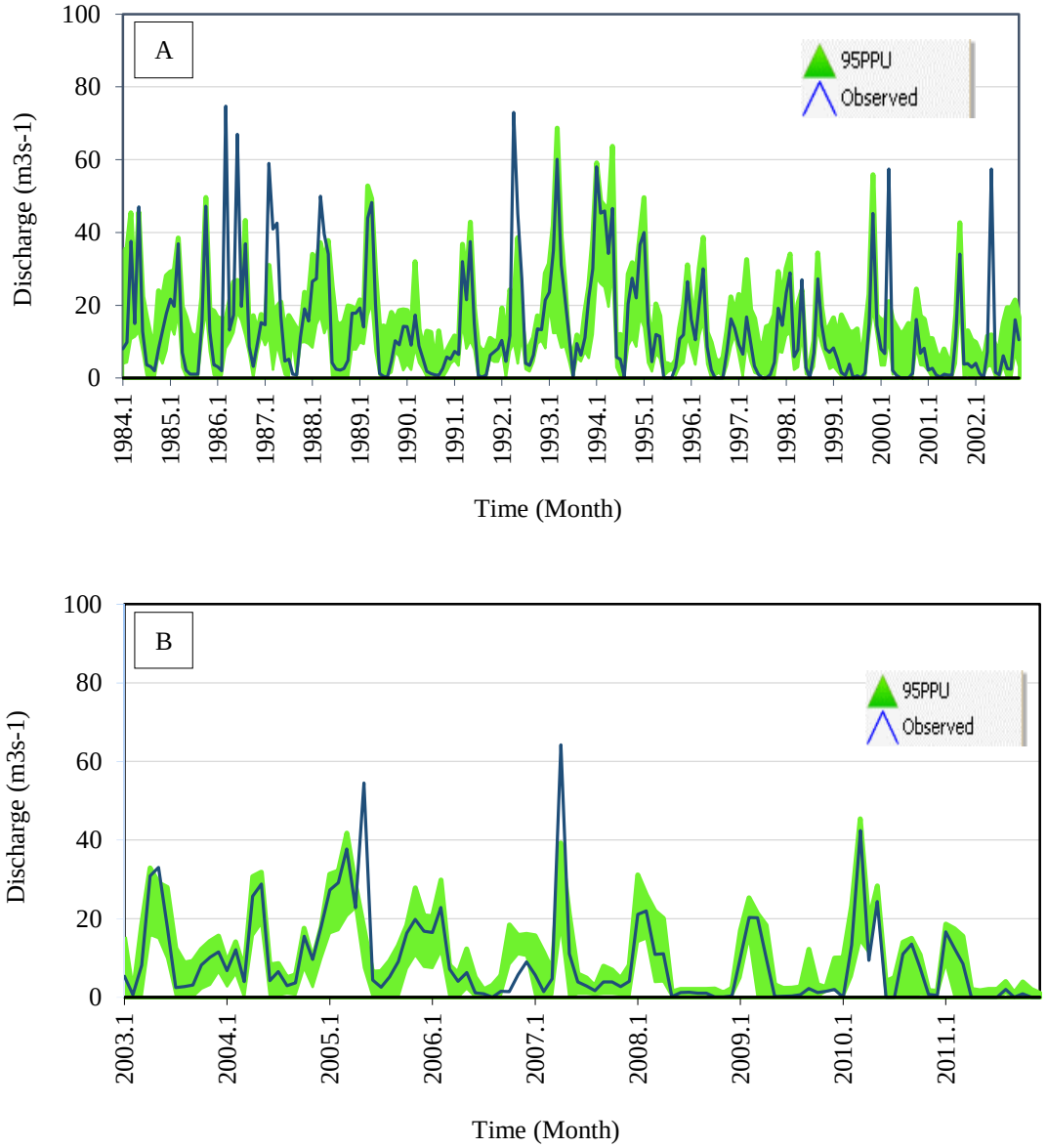

Figure 3 Comparison of the observed and simulated monthly discharges at the Basirabad station for the (A) calibration period and (B) validation period

Table 3 Results of discharge calibration and validation at the 14 hydrometric stations

Hydrometric station	Calibration (1984–2002)		Validation (2003–2011)	
	NS	R^2	NS	R^2
Discharge station				
Tamer	0.53	0.63	0.59	0.68
Haji Ghoshan	0.61	0.73	0.60	0.73
Ghareshoor	0.58	0.66	0.58	0.69
Gonbad	0.70	0.83	0.72	0.83
Araz Kose	0.60	0.70	0.61	0.72
Ghazaghli	0.69	0.75	0.71	0.84
Shirabad	0.54	0.68	0.59	0.69
Basirabad	0.70	0.78	0.71	0.81
Kaboudvall	0.52	0.60	0.55	0.66
Node	0.48	0.58	0.50	0.68
Tilabad	0.58	0.66	0.52	0.63
Sormerood	0.51	0.62	0.57	0.68
Zaringol	0.79	0.90	0.65	0.75
Galikesh	0.59	0.70	0.58	0.69

Although Nash-Sutcliffe coefficient in Sormerood, Nodeh, Tilabad, Kaboudval, Shirabad, Galikesh, Gharehshoor and Tamer was acceptable, but this implies that the SWAT model in runoff simulation in sub-river needs more investigations. This problem is also considered in other studies such as Azimi *et al*. (2013).

As it can be deduced from Figure 3, calibration and validation (A and B) results showed that SWAT model could be a useful tool in relation to river flow simulation, which has also been emphasized by other investigators (Yang *et al.*, 2007; Feyereisen *et al.*, 2007; Arefi Asl, 2010; Akhavan *et al.*, 2010).

3.2.3 Sediment calibration and validation

Figure 4 (A and B) shows a comparison between the observed and simulated sediment for the calibration and validation periods for Basirabad station. The statistics performance showed that the model was able to represent sediment concentration successfully at Basirabad station. The R^2 and NS values were higher than 0.63 for all calibration and validation periods.

Sediment loads during the peak flood events were over predicted (e.g. February 1992, December 2008 and August 1993). On the other hand, it under-predicted the loads in February 2004. However, the performance of the model in simulating monthly sediment loads was satisfactory with NS=0.63 and NS=0.67 for the calibration and validation periods. The improvement of the SWAT model performance when aggregating the outputs over a longer period has also been observed by other researchers in the region and elsewhere (Schmidt and Volk, 2005;Arefi Asl *et al*., 2010).

Full sediment calibration and validation results for 14 stations of Gorganrood watershed can be found in Table 4.

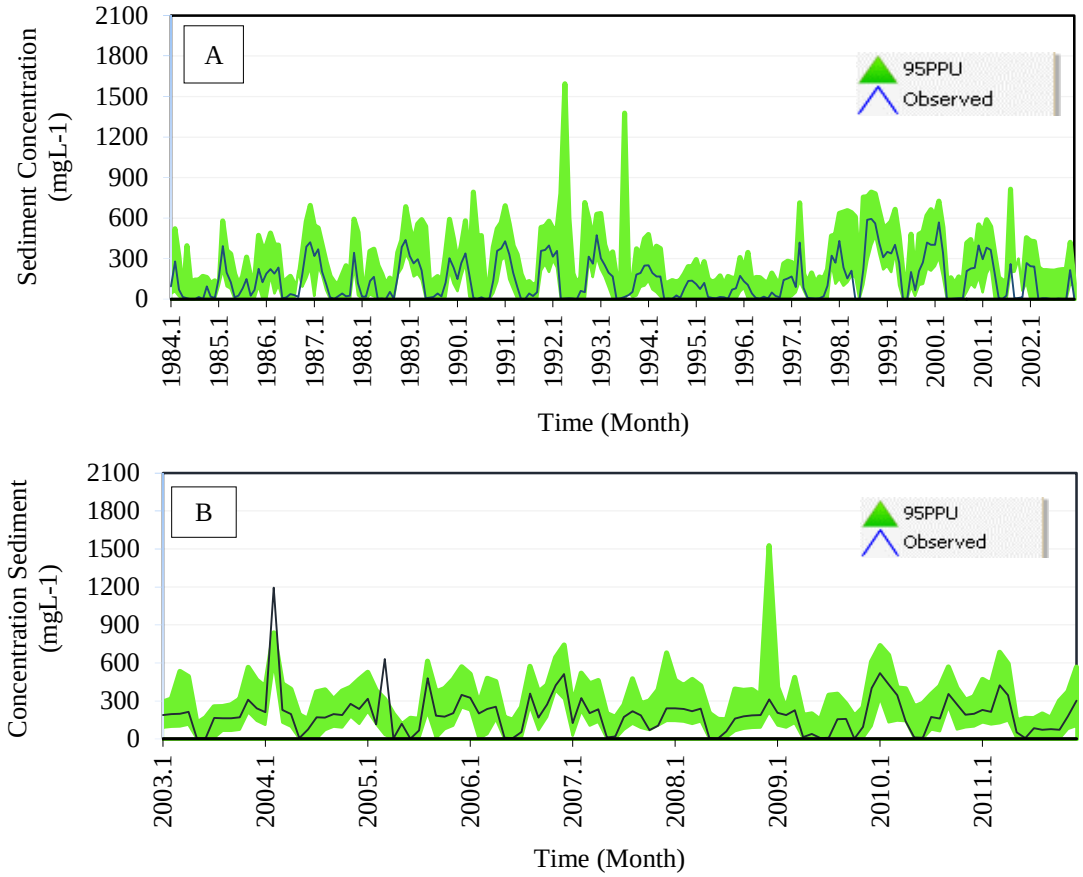

Figure 4 Comparison of the observed and simulated monthly sediment concentration at Basirabad station for the (A) calibration period and (B) validation period

Table 4 Results of sediment calibration and validation at the 14 hydrometric stations

Hydrometric station	Calibration (1984–2002)		Validation (2003–2011)	
	NS	R^2	NS	R^2
Sediment station				
Tamer	0.49	0.59	0.51	0.63
Haji Ghoshan	0.68	0.78	0.59	0.70
Ghareshoor	0.51	0.63	0.55	0.66
Gonbad	0.65	0.76	0.65	0.77
Araz Kose	0.58	0.68	0.63	0.73
Ghazaghli	0.61	0.72	0.65	0.75
Shirabad	0.50	0.61	0.58	0.68
Basirabad	0.63	0.79	0.67	0.83
Kaboudvall	0.53	0.61	0.54	0.68
Node	0.49	0.58	0.59	0.72
Tilabad	0.51	0.63	0.51	0.63
Sormerood	0.52	0.62	0.53	0.66
Zaringol	0.62	0.72	0.62	0.73
Galikesh	0.57	0.82	0.55	0.68

The main problem in estimation of sediment is the lack of enough information and because of this problem, the model for sediment simulation requires runoff calibration.

The results were somewhat more sensitive for the simulation of sediment rate. For example, the NS coefficient value for discharge was 0.59 in Tamer hydrometric station, but it was 0.51for sediment in the same station. The main reason perhaps is that the parameters that have been used have more effect on runoff simulation than sediment simulation. For example, the slope of water channel may cause lots of changes on the transport power of the river or runoff. The same result was also observed by Wang *et al.* (2010).

Rostamian *et al*. (2008) developed a model for Beheshtabad basin (North Karoon) and declared that the weaker simulation of sediment than that of runoff might be due to the lack of enough data for sediment. Yang *et al.* (2007) estimated the value 0.53 for both coefficient of determination and NS coefficient for sediment in calibration period, and 0.4 and 0.37 in validation period, respectively. Similar to discharge, simulation of sediment in permanent rivers with high volume of water was better than seasonal rivers.

By ensuring the calibration and validation of the model, output results of sediment and runoff in sub-basins were calculated and schematized in Figure 5. It can be seen that the runoff and sediment yield modulus in the southern and eastern area are generally bigger than those in northern and western areas. Comparison of runoff map and DEM showed that the critical sub-basins are located in mountainous and hilly areas. Higher rainfall occurs in the southern area and lower rainfall in the northern sub-area. The runoff in the western area also had a higher erosion load because of its steeper slopes. For example, in sub-basins 1, 4, 5, 6, 7, 9 and 13, rate of runoff transfer was more than sediment yield. The sediment yield of the watershed was the amount of sediment moved out of the sub-basin. In the study area, not all eroded soil was transported out. It can be concluded that sub-basins 16, 17, 22, 24, 41, 49, 54, and 60 have different sediment yields (Figure 5). This is mainly due to the different slopes in these areas. Type of land use is very important in the hilly area because mostof the rain-fed lands are located in this area, which are lithologically more vulnerable to erosion and sediment yield. Agricultural practice is certainly another reason responsible for the high runoff rate and sedimentation in steep lands. Ababaei and Sohrabi (2009) and Kim *et al*. (2009) also emphasized on the role of slope.

3.2.4 Nitrate loss

Following calibration of the model using observational data of runoff and sediment concentration and also correcting the input parameters, the model was able to simulate losses of nutrients. The sub-watersheds 3, 17, 20, 24,26,33, 25, and 60 showed high rates of nitrate loss (Figure 6). These sub-watersheds were under dry and irrigation farming, respectively. In the sub-watersheds with agricultural land, the amount of nitrate loss was higher than other watersheds, because the remains of pesticides and chemical fertilizers could move into the rivers by leaching from the soil surface and surface runoff. Sub-watersheds dominated by agricultural practices had high losses of nitrate. This is mainly due to bare soil surface during a period of time in a cropping year, which has also been specified by others (Vander Zanden *et al*., 2005). Hydrological characteristics of arable lands and soil characteristics have significant effects on nitrate loss. Rydin *et al.* (2000) showed that early sowing of winter wheat reduces the risk of nitrate losses in the soil and therefore the risk of leaching would be reduced.

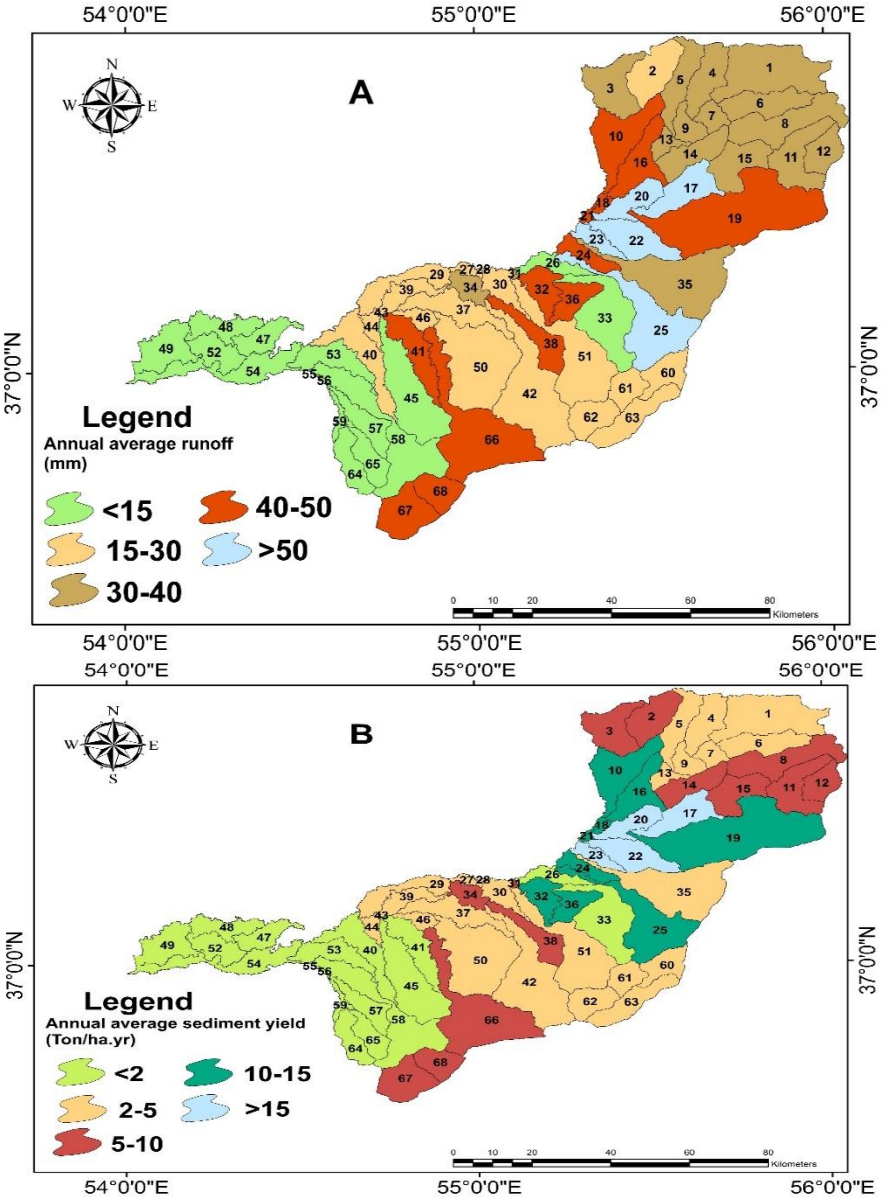

Figure 5 Spatial distribution of the annual runoff (A) and sediment yield (B) of each sub-watershed

Nitrate loss in rangelands was much lower than its loss in agricultural lands (Figure 6). In rangelands, plant roots endured the whole year and at least for 3 years in the soil, which can explain the inherently low losses of nitrate from rangelands or pastures. Grasslands are considered to be ideal for the simulation, but no information related to grazing and mowing was available to apply in the model. Inclusion of grazing and mowing in the model will increase the amount of nitrate leaching due to residual manure (Rydin *et al*., 2000).

As it can be deduced from Figure 6, the amount of nitrate loss was reduced by approaching the river mouth sub-basins (i.e. 29, 34, 39, 40, 45, 47, 48, 52, 53, 54, and 57).

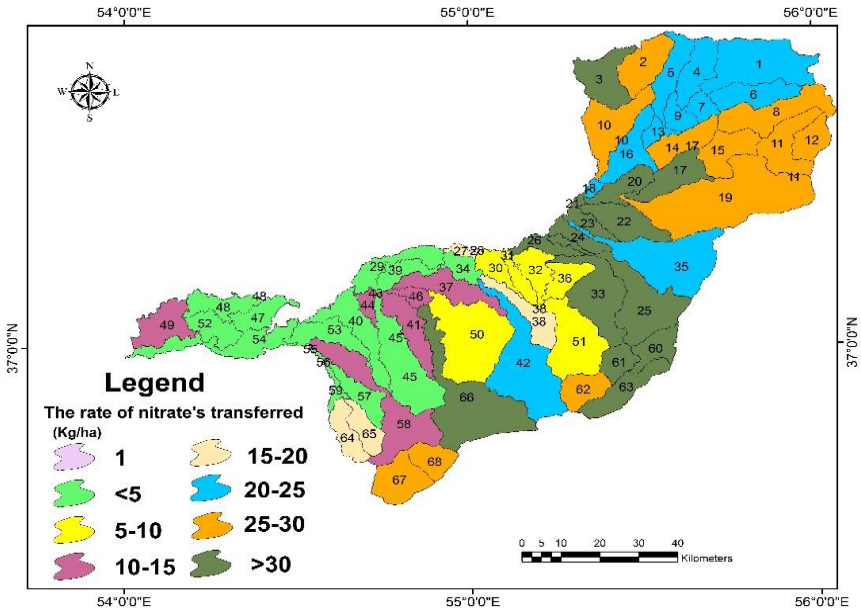

Figure 6 Spatial distribution of the annual nitrate loss in each sub-basin

To ensure the accuracy of the simulation model with regard to nitrate, the nitrate loss achieved by model can be compared with the nitrate concentration in groundwater. Figure 7 illustrates a regression model between the observed average annual nitrate concentration (2008-2011) and simulated nitrate loss and the best fit line. A high value of coefficient of determination (0.7223) indicated a close relationship between the observed and model discharge data. A close relationship between the means and standard deviation of the observed and model data showed that the frequency distribution was similar. Also, a lower value of relative error (0.072) indicated there was a good relationship between observed and simulated nitrate loss in the period 2008 - 2011.Table 5 shows runoff, sediment yield, nitrate simulation and nitrate observation and its relationship with land use and soil texture.

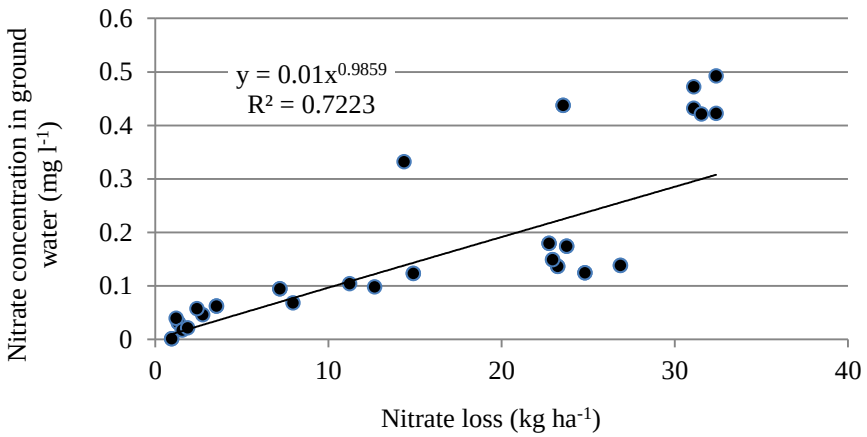

Figure 7 Comparison of the observed and simulated nitrate loss (2008-2011)

Table 5 Runoff, sediment yield, nitrate loss and nitrate concentration at the sub-basin of Gorganrood watershed

Sub-basin number	60% of land use	60% of soil texture	Sediment yield (ton ha^{-1})	Runoff (mm)	Annual average nitrate concentration (mg l^{-1})	Annual average nitrate loss (kg ha^{-1})
10	Mixed dryfarming-Irrigated crops	Silt-loam	16.51	45.32	0.13	23.24
12	Mixed dryfarming-Irrigated crops	Silt-loam	6.01	44.32	0.17	25.74
13	Mixed dryfarming-Irrigated crops, Mixed forest	Silt-clay	3.92	37.16	0.13	25.56
14	Mixed dryfarming-Irrigated crops, Irrigated crop land	Silt-clay-loam	7.25	33.73	0.14	26.96
17	Mixed dryfarming-Irrigated crops, Mixed forest	Silt-loam and Silt-clay- loam	17.61	71.66	0.40	34.82
18	Water	Silt-loam	14.87	47.77	0.10	19.39
20	Agricultural land- row crops	Silt-loam	16.38	58.23	0.43	31.11
28	Mixed dryfarming-Irrigated crops	Clay and Silt-clay-loam	3.41	14.56	0.10	16.96
29	Agricultural land- row crops. Irrigated crop land	Silt-clay-loam and Clay	2.80	11.17	0.06	3.21
30	Agricultural land- row crops	Clay and Silt- clay-loam	4.70	12.21	0.07	6.54
31	Agricultural land generic	Silt-loam and Silt-clay- loam	6.57	38.54	0.09	7.76
33	Agricultural land generic. Mixed forest	Silt-loam and Silt-clay-loam	1.70	14.19	0.42	34.91
35	Mixed forest. Irrigated crop land	Silt-loam	1.70	34.47	0.23	26.35
36	Agricultural land generic	Silt-clay-loam	2.12	34.63	0.10	6.24
40	Agricultural land generic	Silt-clay, Silt-loam	2.30	17.32	0.01	2.67
41	Agricultural land generic	Silt-clay, Silt-loam	1.65	48.21	0.13	14.38
42	Mixed forest	Silt-loam	6.74	29.41	0.16	17.96
45	Agricultural land generic	Silt-clay, Silt-loam	1.20	11.12	0.03	3.29
48	Agricultural land- row crops. Barren	Silt-clay	1.90	11.11	0.04	3.56
49	Agricultural land- row crops	Silt-loam	1.70	11.87	0.12	11.89
50	Agricultural land generic	Clay-loam	2.50	29.41	0.08	7.75
53	Agricultural land generic. Row crops	Silt-clay-loam	1.30	14.87	0.02	3.55
60	Agricultural land row crop. Forest	Silt-loam	2.80	22.21	0.45	32.41
63	Pasture. Agricultural land- row crops	Silt-loam	2.20	25.23	0.42	32.52

The minimum and maximum values for sediment yield were 1.2 ton ha^{-1} y^{-1} and 17.61 ton ha^{-1} y^{-1},which correspond to the sub-basins 45 and 17, respectively. The sub-basins 29, 48, 50 were characterized by a relatively flat terrain with the whole area having slope less than or equal to 17% and predominantly an agricultural and dry farming area while most of

the sub-basin 17,19 and 25 have steep slopes (>17%) with almost equal distribution of rangelands, pasture and forest areas. The amount of nitrate loss in the sub-basins located in the agricultural lands was higher than the other basins. In general, nitrogen pollution is higher in the areas with human activity, such as agricultural lands (Shen *et al*., 2009). The greatest nitrate concentration was found in the sub-basins 17, 20, 33, 60 and 63 with silt-loam and silt-clay-loam soil texture, while the lowest nitrate concentration was found in the sub-basin 29 and 40 with clay and silt-clay, silt-clay-loam and clay-loam soil texture.

4 CONCLUSION

A simulation of sediment yield, runoff and nitrate losses was estimated for Gorganrood watershed. Sensitivity analysis was performed and 24 parameters were found to be sensitive to runoff, sediment and nitrate losses. In general, SWAT model successfully simulated monthly runoff, but simulation of monthly sediment yield was less accurate. R^2(0.60) and NS (0.50) values, bothin calibration and validation exhibited high performance of SWAT in simulating the discharge from the study sub-basin. However, some stations had low coefficients. Although agricultural land uses showed a greater impact on nitrate loss, forest and rangeland also played a great role in this respect. Slope, rainfall and the dry farming performed in steep areas produced maximum runoff and sediment yield. So, the model seems to be robust and can be comparatively accurate simulation for runoff and sediment yield. However, it could not capture dynamics of sediment load delivery in some seasons. By and large, the analytical framework in this study can be used to predict sediment yield and nitrate losses for the assessment of soil fertility and deterioration of natural resources in arid and semi-arid environments.

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کاربرد مدل SWAT در شبیه‌سازی رواناب، رسوب و نیترات حوضه آبخیز گرگانرود ایران

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چکیده

کارائی مدل SWAT و شبیه‌سازی رواناب رسوب و نیترات حوضه آبخیز گرگانرود (استان گلستان) برآورد شد. با توجه به اطلاعات موجود، ابتدا پایگاه داده‌های مکانی با دقت مناسب برای حوضه تهیه شد. سپس مدل در دوره زمانی ۳۱ ساله اجرا شد.واسنجی و اعتبارسنجی داده‌های شبیه‌سازی شده و مشاهداتی، توسطSWAT-CUP و الگوریتم SUFI-2 در ۱۴ ایستگاه هیدرومتری موجود در حوضه انجام شد. مقادیر ضرایب NS و R^2 برای ۱۴ ایستگاه هیدرومتری به‌ترتیب بین ۰/۴۸ تا ۰/۸۳ و ۰/۵۸ تا ۰/۹۰ به‌دست آمد. در حوضه گرگانرود، زمین‌هایی با کاربری کشاورزی و رسوبات لسی بیشترین میزان هدررفت نیترات و مناطق شیبدار با کاربری زراعت دیم بیش‌ترین میزان رواناب و رسوب را به خود اختصاص دادند. نتایج کلی نشان دادند که مدلSWAT توانست رواناب، رسوب و هدررفت نیترات را به خوبی شبیه‌سازی نماید.

کلمات کلیدی:مدل SWAT، SUFI-2، رواناب، رسوب، هدرروی نیترات