Modeling of a River Basin Using SWAT Model and GIS

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ABSTRACT
This paper presents the hydrologic modeling for the development of management scenario and the simulation of the effect of management practices on water and sediment yielding in Gharasu watershed (5793 km^2) using the Soil and Water Assessment Tool (SWAT2000) model. This basin is located in the north west of Karkheh River Basin in the far western corner of Iran. The SWAT2000 interfaced with Arc View GIS data layers including digital elevation model (DEM), land cover and soil map by AVSWAT2000 software. The model was calibrated from 1991 to 1996 and validated from 1997 to 2000. The calibrated model for hydrological conditions was used to assess suspended sediment load. Eventually, the model was used to predict the effect of changing land use and conservation practices on sediment yield within the basin.

Keywords: Karkheh Basin; sediment yield; simulation; SWAT; land use impact.

1 Introduction

Soil erosion in Iran is a wide spread problem threatening the sustainability of agricultural productivity and causing the deterioration of both land and water resources. Intense erosion and sedimentation in the Karkheh River Basin has been primarily caused by over–grazing, dry farming on steep slopes and deforestation. 19% of the upper watershed's rangelands and 70% of its forests hare been significantly degraded [3]. Unless erosion is controlled, sedimentation will significantly reduce the storage capacity of the Karkheh dam reservoir. The Karkheh River Basin has an average sediment yield of 920 tones per km^2 each year which is one of the country's highest [3]. Therefore, the objective of this study is to determine soil erosion and sedimentation transport loading pattern, in Gharasu River Basin, one of the sub-basin of Karkheh River Basin, and evaluate management practices that would potentially reduce erosion within these sub-basins. The main problem of Gharasu basin is conversion of rangelands to rain fed crop in hilly lands without any conservation practices. This causes high erosion because most of the fields are located on steep slope. SWAT has been chosen for this study because it can be used in large agricultural river basin scales and it is easy to use for simulating crop growth and agricultural management.

2 Model Description

SWAT (Soil and Water Assessment Tool) incorporates features of several ARS (Agricultural Research Service) models and is a direct outgrowth of the SWRRB (Simulator for Water Resources in Rural Basins) model (Williams et al., 1985; Arnold et al., 1990). SWAT can be used to simulate a single watershed or system of multiple hydrologically connected watersheds. Each watershed is first divided into sub-basin and then into hydrologic response unites (HRUs) based on the land use and soil distribution. The water storage components are soil profile, shallow aquifer, deep aquifer and snow cover. A daily water budget is established for each HRU based on precipitation, surface runoff, evapotranspiration, base flow (groundwater and lateral flow), percolation and soil moisture change.

Each HRU is modeled as a "lumped" area, meaning that if a given HRU exists in two different areas of the sub-basin, the impact of the HRU area that is closer to the receiving water is not differentiated from the impact of the HRU area that is farther away from the receiving water. A detailed theoretical description of SWAT and its major components can be found in Neitsch et al. (2002) [8]. SWAT is widely used in the United States and in other regions of the world: exploring the potential impact of reforestation on the hydrology of the upper Tana river catchment and the Masinga dam in Kenya (9753 km^2) [5], hydrologic modeling of the Iroquois River watershed, simulation of hydrologic and sediment loading in connonsville River Basin (1200 km^2) [1], water quality modeling for the Raccoon River watershed (9397 km^2) in west central Iowa [6], sediment, nitrogen and phosphorus loading simulation of Bosque River TMDL in Earth county, Texas [10]. SWAT is being used in Iran. It has been used in hydrologic modeling of small area sub-watersheds (<100 km^2) [9]. In this study, simulation of hydrologic and sediment loading by SWAT has been performed in approximately large basin (5793 km^2).

3 Study Area Ddescription and Input Data

The study area, Gharasu River Basin, is one of the sub-basin of Karkheh River Basin in the far western corner of Iran. It covers an area of approximately 5793 km^2. The elevation of the basin changes from 1237 m to 3350 m and the mean elevation is 1555 m. The average land–surface slope from DEM is 14%. Annual mean temperature of the study area is 14.6 °C, varying from 1.1 °C in February to 27.3 °C in August and annual average precipitation is about 447 mm, ranging from 215 mm to 785 mm. The predominate land use is agricultural which covers about 67% of the basin (Landsat 1993). Wheat and barley are the major crops grown in the basin. 5370 km^2 of the total area of basin is drained into the outlet, where the main gage station, Gharabaghestan, is located. Soil is predominately a heterogeneous mix of silt or clay with some local deposits of sand in lowlands. Soil texture in lowland is clay to heavy clay and poor drainage. Daily weather data for precipitation, maximum and minimum temperature were obtained from the records of the climate stations and rain gage stations for the period 1988 – 2000.

20 years (1980–2000) of monthly rainfall, maximum and minimum temperature, relative humidity, wind speed and solar radiation data of the basin were obtained from two climate stations. Daily stream flow was obtained from 3 stations and TSS obtained from 2 stations for the period from 1991 to 2000 within the basin and the main station located at the outlet of the basin. 1172 discharge and sediment samples were collected for generating monthly TSS. The monthly TSS were used for model calibration and validation. Figure 1 shows the location of the flow, TSS, rain gages and climate stations used in the model calibration. Data layers include DEM (50×50 m), land use (Landsat 1993), soil map and streams shape file. Table 1 summarizes the data used to develop, calibrate, and validate the model.

The basin is divided into 66 sub-basins with the aid of Geographic Information system (GIS) using a DEM and stream network. Each sub-basin is further divided into 437 HRUs, which are determined by unique intersections of the land use-soils within each sub-basin. Each HRU within a given sub-basin can be characterized with a unique set of management practices as crop growth and irrigation. The sub-basin delineation, stream network, main outlet of the basin and boundary of the study area are shown in figure 2. After preparing required data files and information layers, the model was run. Then some initial sets were performed. Independent of numerical calibration, some model inputs and parameters, were updated. These parameters are presented in table 2. All data–driven input parameters in table 2 are constant in the calibration an validation periods.

The snowfall temperature parameter in SWAT2000 (SFTMP) determines whether precipitation falls as snow or rain. According to previous studies, if the temperature of the basin is less than 2 °C most of the precipitation is snowfall [7]. The time concentration for surface runoff in Gharasu basin is about one day. So the surface runoff lag coefficient is reduced from 4 to 1. It means 90% of surface runoff reaches the main outlet of basin in one day. Default SWAT2000 Manning's (n) values for all basins were set at 0.014. Table (6-4) in Neitsch et al. (2002) [8] shows that for natural streams with few threes, stones or brush a Manning's (n) value is 0.05. Therefore, Manning's (n) values for all main and tributary channels in the model were set at 0.05.

4 Initial Ssets

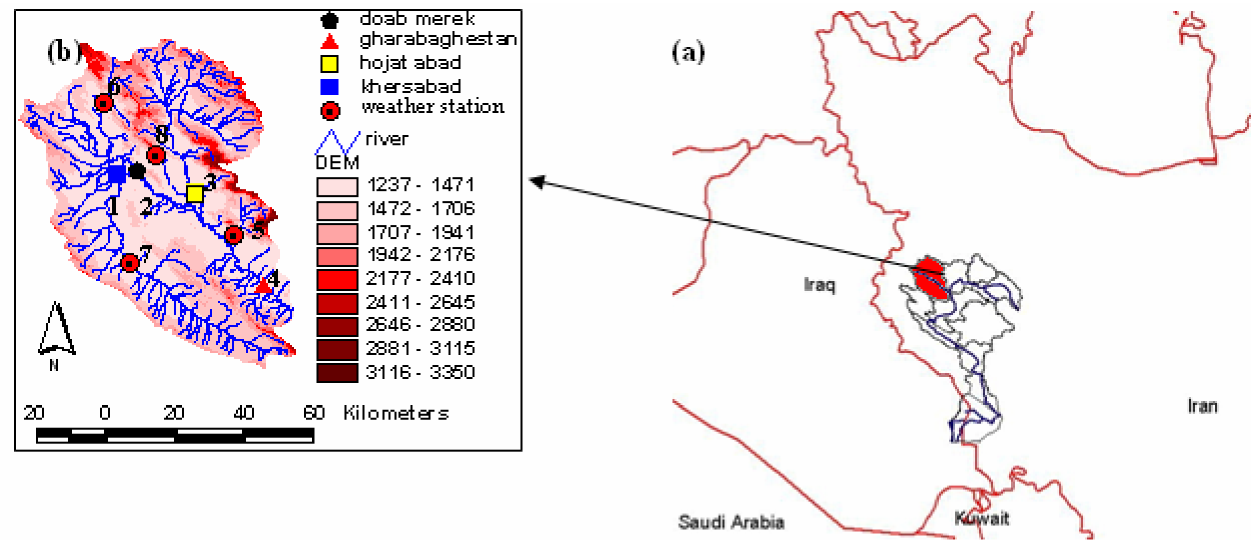

Figure 1 Study area: (a) Location of Karkheh river basin in Iran (b) Location of flow, climate and TSS stations in Gharasu river basin.

Table 1 Summary of data used in model development, calibration and validation.

Data	Location (Number on fig 1-b)	Period of records	Supplying agency	Primary use
Stream flow	Khers abad (1) 1420 km^2	1974-present	IWRM	Calibration and validation
	Doab merek (2) 1232 km^2	1954-present		
	Hojat abad (3) 1325 km^2	1964-1998		
	Gharabaghestan (4) 5370 km^2	1954-present		
Sediment monitoring	Khers abad (1)	1974-present	IWRM	Calibration and validation
	Doab merek (2)	1964-present		
	Gharabaghestan (4)	1962-present		
Climate	Kermanshah (5)	1951-present	IRIMO	Model input
	Ravansar (6)	1988-present		
Rain gage	Mahidasht (7)	1975-present	IRIMO	Model input
	Jelogireh (8)	1976-present		
Land use	Basinwide	1993	RIAEP	Model input
Stream network	Basinwide	Unknown	SCWMRC	Model input
Soils	Basinwide	Unknown	SWRI	Model input
Digital elevation model	Basinwide	Unknown	SCWMRC	Model input

Note: IWRM=Iran Water Resources Management; IRIMO=I. R. of Iran Meteorological Organization; RIAEP=Research Institute for Agricultural Economics and Planning; SCWMRC=Soil Conservation and Watershed Management Research Institute; SWRI=Soil and Water Research Institute.

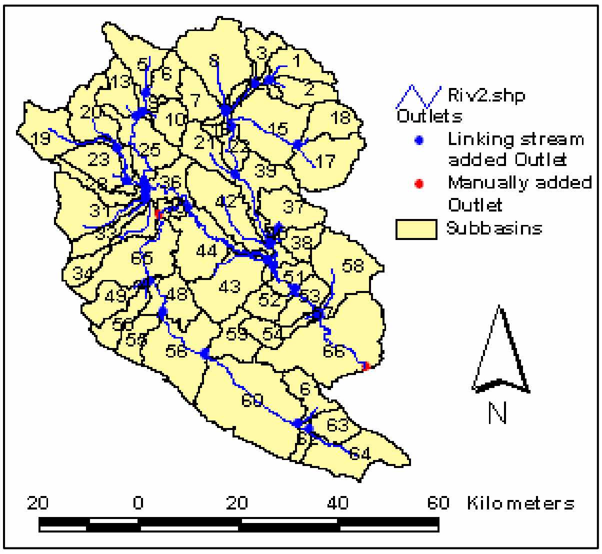

Figure 2 Sub-basin delineation and stream network of Gharasu river basin that generated by AVSWAT2000.

Modeling orographic temperature changes requires SWAT2000 inputs for the definition elevation bands for each sub-basin. Ten elevation bands were created in each sub-basin. The ELEVB_FR and ELEVB parameters for each sub-basin were determined from the toporep.txt output file of AVSWAT. Temperature laps rate (TLAPS) were obtained from analyzing available weather data. The average temperature laps rate is 5 °C within the basin. The Manning's (n) value for overland flow (OV_N) was chosen according to table (6-3) in Neitsch et al. (2002) [8] for each HRU. LAT-TTIME was calculated for each HRU according to soil properties and slope length of the HRU. In the mountainous and plain area it was estimated about 5 days and 25 to 40 days respectively.

4 Hydrology Calibration and Validation

For the Gharasu basin, SWAT2000 was calibrated over 6 years, from January 1991 to December 1996. 4 years (1987 to 1990) were chosen as a warm-up period in which the model was allowed to initialize and then approach reasonable starting values for model state variables. Model predictions are not evaluated in accordance with the 4-year warm-up period until another 4 full years have been simulated. The model was validated over 4 years, from January 1997 to December 2000. The longest–running flow gage for the basin drains approximately 93% of the basin (station 4 in fig 1). In addition, the three gages that drain the smaller sub-basins were used during the calibration procedure (Station 1, 2 and 3 in fig. 1). The calibration parameters are presented in table 3. The soil evaporation compensation factor (ESCO) was decreased from the default value 0.95 to 0.4 resulting in more evapotranspiration, especially during the summer months. The snow melt parameters were adjusted to improve winter flow predictions. The SMTMP parameter was increased from 0.5 to 4 °C in order to delay snowmelt until warmer temperature persisted. SMFMX and SMFMN parameter changes improved the peak flow predictions. Base flow alpha factor (ALPHA–BF) was increased to simulate steeper hydrograph recession. The revap coefficient controls the amount of water that moves from the shallow aquifer to the root zone. This parameter was increased to allow more movement of water from shallow aquifer to the unsaturated zone. This parameter was used to adjust summer base flow. GWQMN was increased to create groundwater storage capacity. This parameter controls base flow too. REVAPMN was decreased more than GWQMN, so that groundwater return flow occurs after revap. GW_DELAY was modified to improve model predictions groundwater and summer low flow.

Table 2 Summary of initial modifications of SWAT model.

Parameter	SWAT variable name	Range	Default value	Final value
Snowfall temperature (ºC)	SFTMP	±5	+1	+2
Surface runoff lag coefficient	SURLAG	1-40	4	1
Manning's "n" value for overland flow	OV-N	0.01-0.8	0.15	Engman, 1983 [4]
Manning's "n" value for the main channel	CH-N2	0.01-0.3	0.014	Chow, 1959 [2]
Lateral flow travel time (days)	LAT-TTIME	0-180	0	Calculated and Varied by HRU [8]
Temperature lapse rate (ºC/km)	TLAPS	0-50	6	5
Elevation at the center of the elevation band (m)	ELEVB	0-8000	0	Determined from
Fraction of sub-basin area within the elevation band	ELEVB-FR	0-1	0	AVSWAT elevation report

Table 3 Initial and final values of SWAT calibration parameters for stream flow.

Parameter	SWAT variable name	Range	Default value	Final value
SMTMP	Snow melt base temperature (ºC)	±5	+1	+4
SMFMX	Melt factor for snow on June 21 (mm H_2O/ºC-day)	0-10	4.5	2.6
SMFMN	Melt factor for snow on December 21 (mm H_2O/ºC-day)	0-10	4.5	2.5
ESCO	Soil evaporation compensation factor	0.01-1	0.95	0.4
ALPHA-BF	Base flow alpha factor (days)	0-1	0.048	0.118[1] 0.098[2] 0.05[3]
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	0-5000	0.5	40[1,2] 20[3]
GW-REVAP	Groundwater "revap" coefficient	0.02-0.2	0.02	0.04[1] 0.06[2] 0.02[3]
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (mmH_2O)	0-500	1	20[1,2] 10[3]
GW-DELAY	Groundwater delay time (days)	0-500	0	Varied by HRU

1. The area of basin that drained into Khers abad station (Number 1 on the map of Fig. 1) (1420 km^2).
2. The area of basin that drained into Doab merek station (Number 2 on the map of Fig. 1) (1232 km^2).
3. The area of basin that drained into Hojat abad and Gharabaghestan stations (Number 3 and 4 on the map of Fig. 1) (2718km^2).

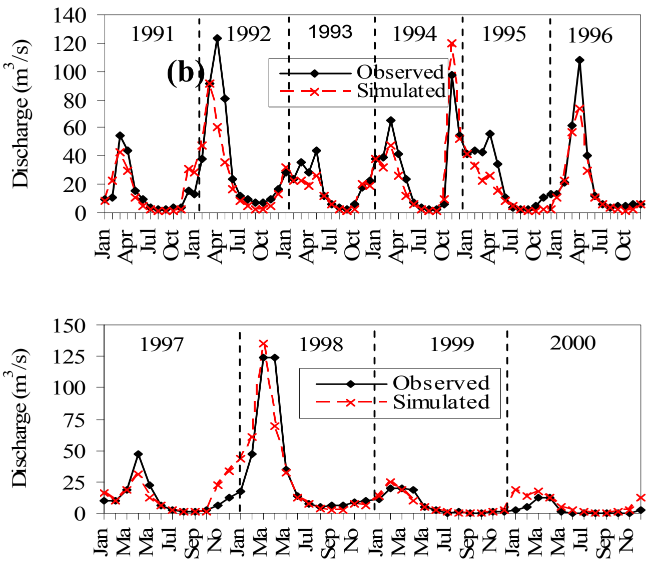

Figure 3 Comparison between observed and simulated monthly stream flow at Gharabaghestan (station 4) for: (a) Model calibration (b) Model validation.

The time series of the observed and simulated monthly flow for the calibration and validation period were compared graphically (Figure 3) in the main outlet of the basin (station 4). The simulated flow of January, February and March is more than the observed flow in 1992, and it is less than the observed flow in April and May. It seems simulated snowmelt accurse sooner than actual time. The coefficient of determination, R^2, and the coefficient of efficiency, $E_{N\text{-}S}$, were used to evaluate model predictions. The calibration and validation results for stream flow are presented in table 4 at four stations within the basin.

5 Sediment Load Calibration and Validation

The TSS prediction of the model was calibrated at the gage site 1 and 2, and then calibrated at the outlet of the basin from 1991 to 1996. Some parameters used to simulate TSS were driven from available data or known conditions in the watershed. A relatively small group of model parameters were adjusted to best match measured TSS data. These parameters are presented in Table 5.

Table 5 Initial and final values of SWAT calibration parameters for TSS

Parameter	SWAT variable name	Range	Default value	Final value
USLE-P	USLE equation support practice factor.	0.1-1	0	1
USLE-K	Soil erodibility (K) factor (units: 0.013 (metric ton m2 hr)/(m3-metric ton cm)).	0-0.65	0	Mountain (0.3) Hill (0.4) Other areas (0.27)
USLE-C	Minimum value of USLE C factor for water erosion applicable to the land cover/plant	0.001-0.5	Agricultural land (0.03)	0.03
			Range (0.003)	Good (0.002) Fair (0.003) Poor 0.004)
			Forest (0.001)	0.001
ROCK	Rock fragment content (% total weight).	0-100	0	Varied by soil type

The USLE equation support practice factor (USLE_P) was chosen as 1. It means that farmland in the basin, is not managed or supported. The USLE_K factor was chosen for each type of soil attending soil texture and organic matter content. Minimum USLE_C factor was changed from the default value for a fair range. It's increased for poor ranges and decreased for good ranges. The percent of rock in the first layer of soil profile was not changed from base value (data-driven). Surface runoff is the most effective propellant on sediment yielding. So the CN (Curve Number) parameter was increased 5% to increase surface runoff and lateral flow was decreased to better match measured TSS data. Other parameters related to stream channel erosion were not modified from their default values because their modification did not result in significantly better model predictions. Average annual sediment yield of Gharasu basin is predicted 3.4 ton/ha by SWAT model. The result of calibration and validation for TSS simulation at the main outlet of basin is shown in figure 4.

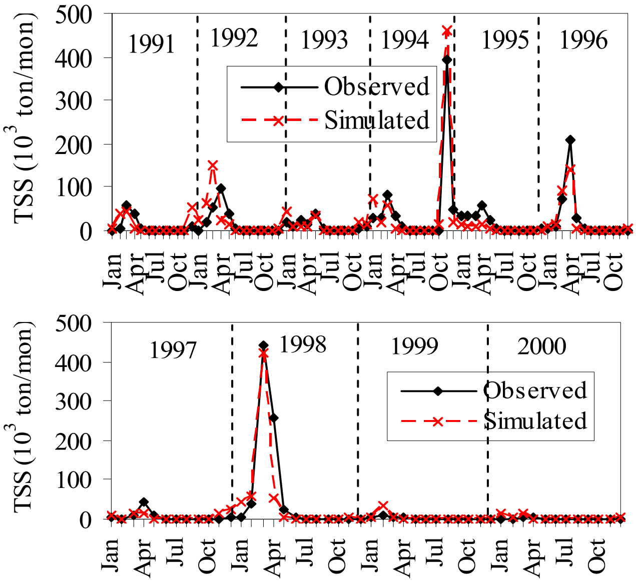

Figure 4 Comparison between observed and simulated monthly TSS at Gharabaghestan (station 4) for: (a) Model calibration (b) Model validation.

Consistent with hydrology results, figure 4 demonstrates that at the main outlet of basin the model tends to increase TSS loading sooner in the winter of 1992 associated with snowmelt. The most severe errors in predicted TSS loads all occur in months where there are large predictive errors in the monthly flow. The calibration and validation results for TSS are presented in table 4 at the stations within the basin.

Table 4 Summary of calibration and validation results for monthly stream flow and TSS simulation.

	Monitoring station	Calibration R^2	Calibration E_{NS}	Validation R^2	Validation E_{NS}
Monthly stream flow	Khers abad	0.89	0.90	0.91	0.50
	Doab merek	0.85	0.87	0.94	0.93
	Hojat abad	0.80	0.78	0.86	0.85
	Gharabaghestan	0.72	0.71	0.71	0.70
Monthly TSS	Khers abad	0.96	0.80	0.99	0.90
	Doab merek	0.71	0.59	0.87	0.86
	Gharabaghestan	0.84	0.63	0.82	0.82

After sureness of model validity, the erosion map of sub-basins was provided. It is schematized in figure 5 from 1997 to 2000. By using this map the critical sub-basins were specified (Fig. 6). Comparison of erosion map and DEM showed that the critical sub-basins are located in mountainous and hilly areas. Moreover, comparison of sediment yield of HRUs indicates the most erosive areas are cultivated lands with steep slope. Some factors which here more influence on the erosion of critical sub-basins are compared in table 6. As shown in table 6 the slope of these sub-basins are significantly more than 14% (average slope of the Gharasu basin). Considering the erosion pattern of HRUs, we can see that natural processes such as rainfall intensity and geomorphology are the main causes of soil erosion in Gharasu river basin, but large area are affected by accelerated erosion caused by removal of natural vegetation cover.

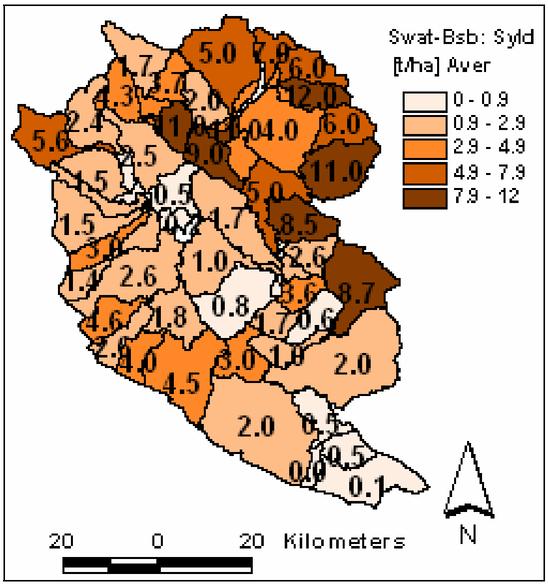

Figure 5 SWAT model predicted sediment yield per hectare of sub-basin from 1991-1996.

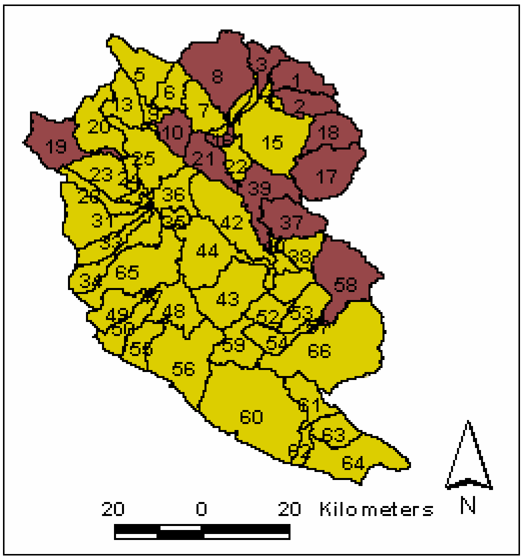

Figure 6 Sensitive sub-basins to erosion (dark color).

Table 6 Comparison of more influence erosion factors of critical sub-basins.

Sub basin	Predicted sediment yield (ton/ha)	Yearly precipitation (mm)	Slope (%)	Predicted surface runoff (mm)	Hill (%)	Mountain (%)	Predominate land use
1	6.2	470	27	88	10	86	Poor range
2	11.8	464	24	80	16	56	Poor range and rain-fed land
3	6.9	520	21	56	71	29	Rain-fed land and good range
8	5.1	535	16	66	33	38	Rain-fed land and fair range
10	11.0	472	24	59	0	73	Fair range
16	11.3	472	35	80	0	67	Fair range
17	8.0	472	18	80	43	54	Rain-fed land
18	6.0	472	20	67	39	51	Rain-fed land
19	5.7	471	19	56	52	37	Rain-fed land
21	8.9	597	31	99	6	86	Rock cover and poor range
37	5.1	472	38	60	0	44	Rain-fed land and poor range
39	8.4	472	21	60	0	52	Rain-fed land and poor range
58	8.7	426	45	45	0	64	Rock cover and rain-fed land

Reduction in vegetation cover is caused by conversion of rangeland to rain fed crops, overgrazing and deforestation. In the studied area, the main cause of land use change is the need for agricultural land. Therefore, range land is converted to rain fed land in the hilly areas. Land use type of hilly area is very important because most of the rain fed lands are located in this area and the type of geology is low to medium resistance to erosion; so it has more erosive power and production of sediment yield. Irrigated agricultures are concentrated in the alluvial area and along the valley due to gentle slopes and its productive soils. Because of the gentle slope and heavy soil texture, little erosion occurs in these regions. With consideration of the above explanations, some management practices are recommended for soil conservation:

1- Support practices such as contouring and terracing.
2- Land cover change in hilly and mountainous areas of basin with consideration of land capability.

First scenario: With due attention to topographic conditions and possibility of "contouring" or "contouring and terracing" the critical sub-basin 16, 17, 19, 37 and 39 are suitable for land management practices. Reduction of erosion in the agricultural HRUs located in lower parts of these critical sub-basins is presented in table 7. As shown in table 7, contouring and terracing is more effective than contouring.

Second scenario: Because land management practices in hilly and mountainous areas are impracticable, land cover changing of these areas is recommended for soil conservation. The best suggestion most suitable for each land use was found. The hilly areas are suitable for afforestation. Therefore, rain fed lands and other land uses located in hilly areas are converted to forest. The land cover of hillsides is converted to orchard. Finally, the mountainous areas are suitable for pasture and range. The results of land use conversion are presented in table 8. The best effect of the land use conversion on sediment yield reduction occurs in sub-basins that rain fed lands on hillsides are predominate land use (sub-basin 3, 8 and 19). Sediment yield reduction of mountainous sub-basins is negligible (sub-basin 10, 16, 37 and 39). In these sub-basins the main factor of erosion is steep slope, and land use conversion isn't effective.

6 Results and Discussions

Two different management scenarios for soil conservation were considered in order to evaluate the effects on sediment yielding in Gharasu river basin. Contouring and terracing will effectively reduce sediment loading of rain fed lands in hillsides. Changing agricultural practices such as increasing forest, conversion of rain fed area in steep slope land to orchards and woods will reduce erosion about 5 percent within hilly and mountainous sub-basins. Finally, this study showed that SWAT model is a capable tool for simulating hydrologic components and erosion in Gharasu river basin.

Table 7 Summary of support practices results on sediment yield

Sub-basin	Area of HRU (%)	Initial sediment yield (ton/ha)	Predicted sediment yield (ton/ha)		Sediment yield reduction of sub basins (%)
			Contouring (Reduction %)	Contouring and Terracing (Reduction %)	
16	9	26	21 (19)	16 (38)	5
	3	0.7	0.3 (57)	0.3 (57)	
17	3	30.9	25.6 (17)	20 (35)	1
19	4	14.3	10.4 (27)	7.7 (46)	2
37	3	43.5	35.5 (18)	17 (61)	5
	4	23	21 (8)	14 (39)	
	1.5	1.36	0.0 (100)	0.7 (48)	
39	5	29	24 (17)	18.5 (36)	5
	6	8	5.8 (28)	3.5 (56)	

Table 8 Summary of land use conversion results on sediment yield

Sub-basin	Initial sediment yield (ton/ha)	Predicted sediment yield after land cover changing (ton/ha)	Sediment yield reduction of sub-basins (%)
3	7.26	0.63	91
19	4.32	0.44	90
8	4.94	0.58	88
17	7.7	3.58	53
1	5.44	2.82	48
18	4.90	2.79	43
2	10.65	7.34	31
58	6.70	5.03	25
21	6.54	5.96	9
10	9.10	9.08	0.2
16	8.23	8.24	0.1
37	7.00	7.00	0.0
39	3.78	3.78	0.0

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