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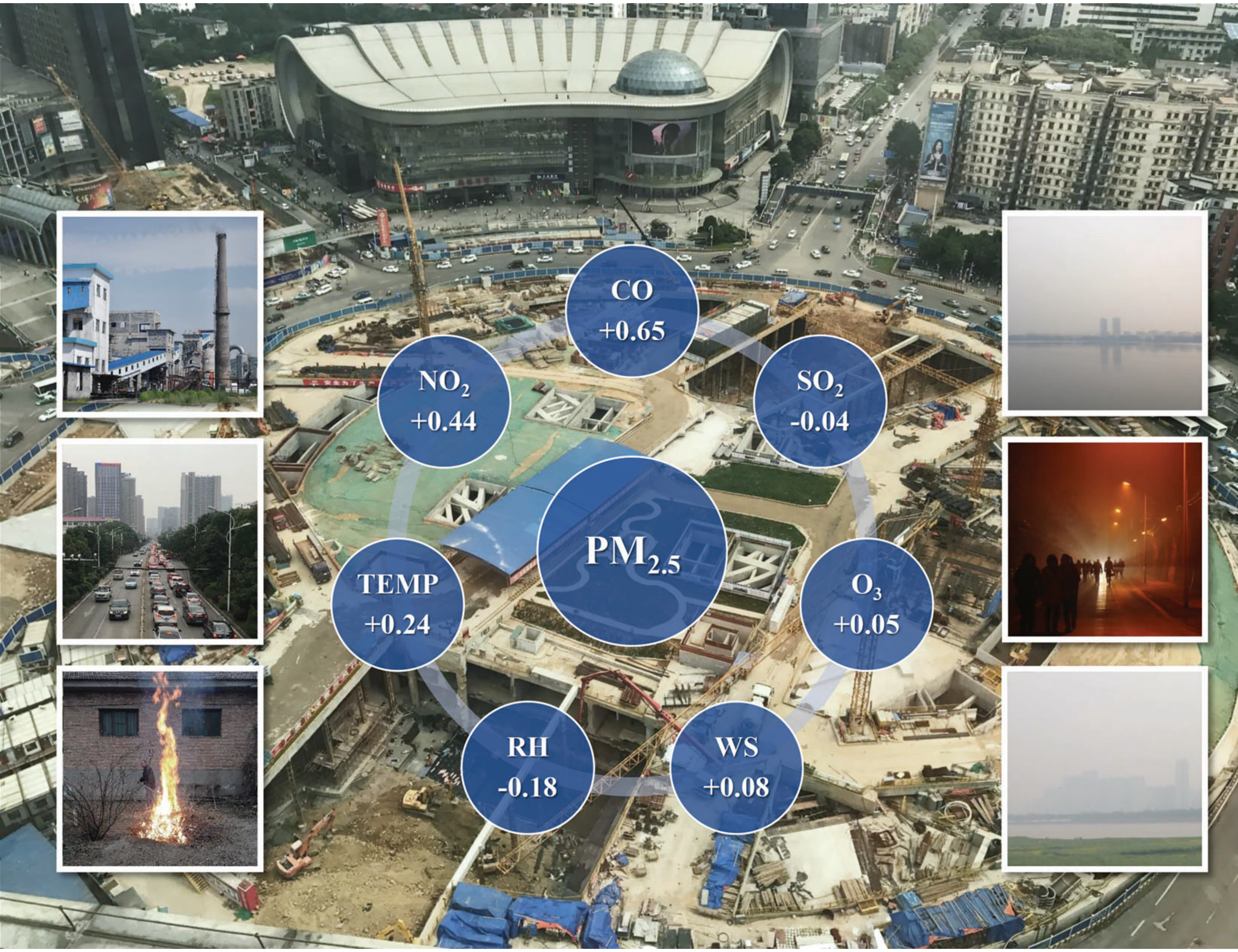

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Soil Air Water

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Research Article

Effectiveness of Soil and Water Conservation Practices Under Climate Change in the Gorganroud Basin, Iran

Assessing the effectiveness of conservation practices under changed climatic conditions has proven to be invaluable in selecting the adaptation practices. Conservationists are concerned that past effective practices may no longer be effective in the future climate change. This research is aimed at assessing the effectiveness of soil and water conservation practices under future climate change, with respect to sediment yield leaving a watershed. For this purpose, the Soil and Water Assessment Tool, SWAT, was applied to simulate various climate change scenarios with three soil and water conservation practices to assess possible changes in stream flow, and sediment yield of the Gorganroud watershed in the northern part of Iran. Study results demonstrated that the impact of climate change in the increase of watershed sediment yield is more than the stream flow and varies from 35.9 to 47.7% for the period 2040–2069. Implementing conservation practices under climate change can reduce the sediment yield of watershed up to 7.2% and for the sub-basin scale up to 46.4%. Range management practices were found to be the most effective practice in the decrease of sediment at the sub-basin scale and porous gully plugs and terrace construction, the most effective at the watershed scale. The results indicate that soil and water conservation practices will be more effective at reducing sediment yields under anticipated future climates. Though, implementation of each conservation practice solely was not sufficient to compensate for climate change-driven increases in sediment yield. This study provides valuable information for watershed managers and decision makers regarding selection of soil and water conservation practices for adaptation to climate change.

Keywords: Future climate scenarios; Greenhouse gas emissions; Mitigation; Stream flow; SWAT

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1 Introduction

Climate change presents a major challenge to sustainable land management. Global climate change is expected to be conducive to the increase of mean surface temperature, precipitation and extreme events, and will continue to increase during the next century [1]. Although the extent of these changes is still uncertain, the overall increase of the average global surface air temperature and further changes in rainfall amount, rainfall intensity as well as the frequency of extreme climatic phenomena are expected [2]. Climate change can lead to increase in soil erosion rates for various reasons, such as the total amount of rainfall and rainfall intensity; however, the dominant variable appears to be rainfall intensity and energy rather than rainfall amount alone [3–6]. Storm runoff and soil erosion, however, can also be governed by other factors, such as soil moisture and vegetation cover [6]. These parameters are also expected to be affected by climate change, making impact quantification a complex problem [7]. More intense and more frequent extreme rainfall events increase soil erosion, accelerating the degradation of soil quality, and diminishing crop yields [6, 8, 9]. Increased land surface runoff in turn will increase sediment loads and affect timing of sediment loss [2, 10].

Several previous studies have been conducted to assess the impact of future climate change on the watershed hydrology [11–24]. A limited number of studies has reported on the potential impact of climate change on soil erosion and sediment yield [25–29]. Previous studies simulating the impact of climate change on watershed hydrology have shown both increases as well as decreases in

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Abbreviations: **BMP**, best management practice; **CGCM2**, Canadian Global Climate Model Version 2; **CN**, curve number; **CSIRO2**, Commonwealth Scientific and Industrial Research Organization Gcm Mark 2; **GCM**, general circulation model; **HadCM3**, Hadley Centre Coupled Model Version 3; **HRU**, hydrological response unit; **MUSLE**, modified USLE; **95PPU**, 95% prediction uncertainty; **USLE**, universal soil loss equation; **SWAT**, Soil And Water Assessment Tool; **SWAT-CUP**, SWAT Calibration and Uncertainty Programs.

sediment yield and stream flow depending on the characteristics of the watershed. Overall, with climate change, the erosion potential is expected to increase by about 25–50% during the twenty-first century [30]. Studies have revealed that the plausible climate change impacts on soil and water resources have been serious enough to warrant increased attention by conservationists on changing policies to prepare for the anticipated impacts of more severe erosion and runoff on soil and water resources [31]. Although some general conclusions regarding climate change and their impacts have been drawn, especially at macro-scales, the potential damages of climate change in specific regions still need to be assessed. Such information is useful for making decisions on management practices to mitigate the adverse impacts of climate change [32]. Management decisions that help us mitigate and adapt to climate change will be key to conservation, the sustainability of cropping systems, soil and water quality, and food security [33]. There is potential to use conservation practices and management to adapt to and mitigate climate change [33, 34]. Agricultural conservation practices, also known as the best management practices (BMPs), are used extensively as effective measures in agricultural watersheds as a means to improving water quality and ameliorating altered hydrology [35]. Conservation practices can improve soil water-holding capacity and storage of water in the soil profile and can help improve soil functions by reducing the potential for soil erosion [30].

Although assessing the effectiveness of current conservation practices under changed climatic conditions have proven to be a complex task, it can still serve as a beacon in selecting the best adaptation to climate change plans [34, 36].

Some studies using results of climate change impacts assessment have focused on effectiveness of BMPs and conservation practices under climate change [10, 37–41]. Studies have demonstrated that BMPs' performance will significantly change in future climate and that there is a strong need to consider these changes in the present day soil and water management. While there is a general consensus that soil and water conservation practices can be one of the promising options for climate change mitigation and adaptation [33], studies focusing specifically on the quantitative assessment of the effectiveness of current practices in soil and water conservation for adaptation to climate change are very limited in the world and even more so in Iran.

Given that current conservation practice strategies for soil and water conservation may not sufficiently cope with future water quality and quantity issues, examining the combined effect of climate change and implementation on conservation practices is an important planning step for water resources managers [41]. Therefore, the goal of the present study was to quantify the effectiveness of soil and water conservation practices under future climate scenarios, with respect to sediment yield leaving a watershed. Specific objectives include evaluating the climate change impacts on sediment yield and stream flow in the Gorganroud river basin, and the effectiveness of three soil and water conservation practices under the present and future climate scenarios. To this end, the Soil and Water Assessment Tool (SWAT) and climate change projected by three general circulation models (GCMs) for the time period of 2040–2069 under three greenhouse gas emissions scenarios were used. The results of the present study can be a useful tool for development mitigation and adaptation strategies in soil and water conservation in the watershed.

2 Material and methods

2.1 Study area

The Gorganroud watershed encompasses an area of approximately 7138 km^2 between 36° 43′–37° 49′ N and 54° 42′–56° 28′ E. The study area is located in the northern part of Iran and drains into the Caspian Sea (Fig. 1). The minimum and maximum elevations of the basin are 10 and 2898 m above sea level, respectively. Although Iran is generally classified as arid and semi-arid, the climate of the Gorganroud watershed is characterized as being semiarid in the east and wet in the western regions. The temperature of the basin ranges between 11 and 18.1 °C annually and the average annual precipitation ranges from 195 to 946 mm in watershed stations. Approximately 36% of the normal precipitation falls in January to March.

In general, the topography of the watershed is characterized by a complex combination of mountains (46.1%), hills (9.6%), plateau and upper terraces (4.6%), Piedmont plains (15.5%), river alluvial plains (16.3%), and low lands (7.7%). Different sedimentary rocks such as limestone, sandstone, shale, dolomite, and marl, along with conglomerate, loess sediments and alluvium cover the area. Based on the new classification system (soil taxonomy) the watershed soils include Entisols, Aridisols, Inceptisols, and Mollisols. Major land uses include agriculture (37%), range land (34%), and forest (28%) and the main crops are wheat, barley, sunflower, and watermelon. The Gorganroud watershed is the population center of Golestan Province in Iran, hosting approximately 1.2 million people. The Voshmgir dam in the outlet of the watershed supports the supply of water to the public, flood control, hydroelectric power generation, and irrigation.

The basin supports an economy based on agriculture (46% of population), industry and mining (20% of population), and contains wildlife habitat. In recent years, population growth has led to land use change in erodible soils and this has accelerated runoff and soil erosion [42]. Due to the above, the Gorganroud River is suffering from accelerated soil erosion, flash floods, and high sediment yield [43].

2.2 The SWAT model

SWAT is a basin scale, process-based, continuous time model that operates on a daily time step. This watershed-scale model was developed by the US Department of Agriculture, Agricultural Research Service in the early 1990s to predict effects of agricultural land management on watersheds and rivers [44]. SWAT has been applied as a powerful tool to quantify the impact of conservation and climate change on water, sediment and agricultural chemical yields in large ungauged basins, for a wide range of scales and environmental conditions across the globe [45, 46]. A hydrological response unit (HRU) is the smallest spatial unit of SWAT for simulating the water balance. In SWAT, HRUs are composed of a unique combination of soil type, land use and slope classes. The sub-basin processes of SWAT include hydrology, erosion, climate, nutrients, soil temperature, plant growth, pesticides agricultural management and stream routing. SWAT simulates the water balance at each HRU using daily precipitation, runoff, evapotranspiration, percolation and return flow values. There are two methods for estimating surface runoff in the model: (i) the Natural Resources Conservation Service curve number (CN) and (ii) the Green and Ampt method. In this study the CN method was applied to simulate surface runoff.

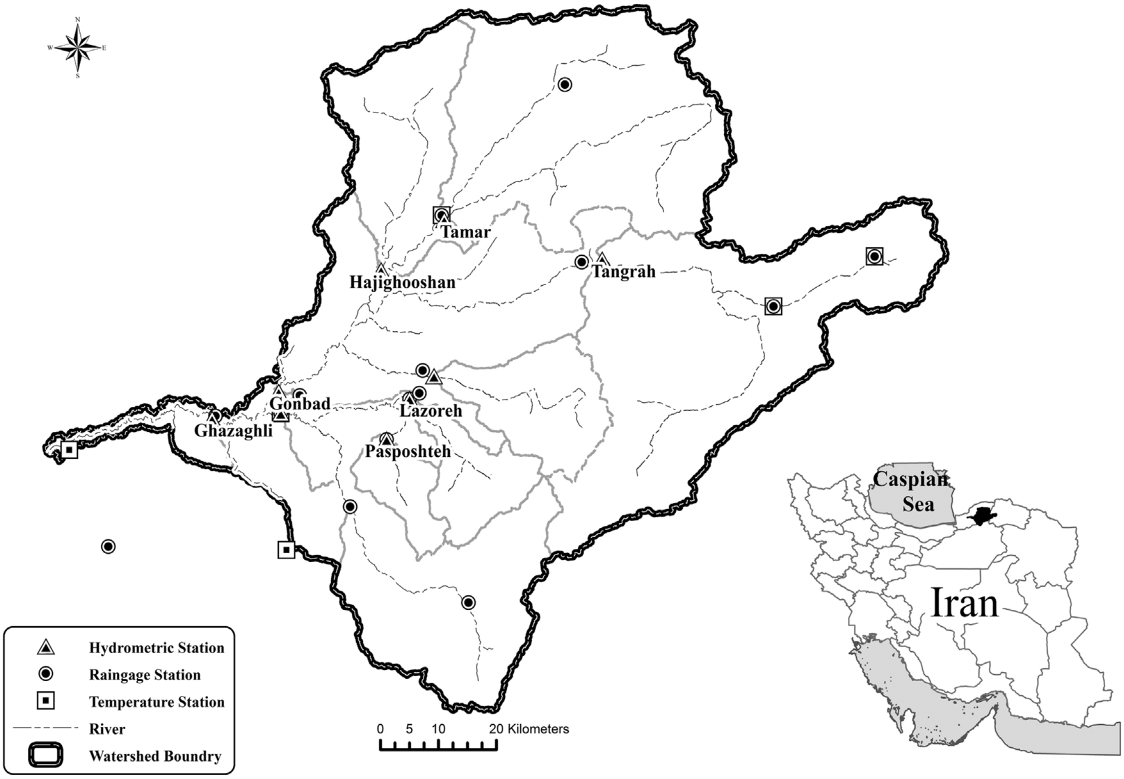

Figure 1. Geographic location of the studied area, hydrometric station and rainfall gauges.

The simulation of hydrological processes of SWAT are conducted in two phases [47]: 1) The land phase, which controls the amount of water, sediment and nutrients received by a water body: and 2) the water routing phase, which simulates water movement through the channel network. The hydrologic cycle of SWAT is simulated on the water balance equation (Eq. (1)).

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

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), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm) [47].

In the SWAT model, erosion and sediment yield are computed for each HRU using the modified universal soil loss equation (MUSLE) [47]. Soil erosion estimation in MUSLE is written as Eq. (2):

$$sed = 11.8\left(Q_{surf}.q_{peak}.\text{area}_{hru}\right)^{0.56} K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times \text{CFRG} \quad (2)$$

where sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 h/(m^3 metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and CFRG is the coarse fragment factor. Estimated sediment yield and stream flow for each sub-basin are then routed through the river using the variable storage coefficient method, or Muskingum method [44]. A key strength of SWAT is a flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs. The majority of conservation practices can be simulated in SWAT with straightforward and physically meaningful parameter changes [45, 46].

2.3 Data and model setup

The SWAT model requirement for setup includes elevation, land use, and soil data. In the present study, the land use map is extracted from the interpretation of Land Sat TM (30 m resolution) satellite imagery, based on field studies, and contains seven land use classes (Fig. 2a). The soil map was attained from the Iranian Ministry of Agriculture, which has 1:250 000 and 1:50 000 scale in the mountainous and plains areas, respectively. The soil map consists of 74 soil units with physical and chemical soil properties extracted from surveys conducted in the study area (Fig. 2b). The daily precipitation data from 15 stations and daily maximum and minimum temperature data for eight stations (Fig. 1) were obtained from the Iranian Meteorological Organization and the Water Resources Management Organization, WRMO, of Iran. Daily discharge data were acquired from the Iranian Water Resources Management Organization. The calibration and validation was carried out using the monthly stream flow data from eight hydrometric stations and the monthly sediment loads predicted by the rating curve as a function of mean daily stream flow for 23 years. The Gorganroud basin was discretized into sub-basins

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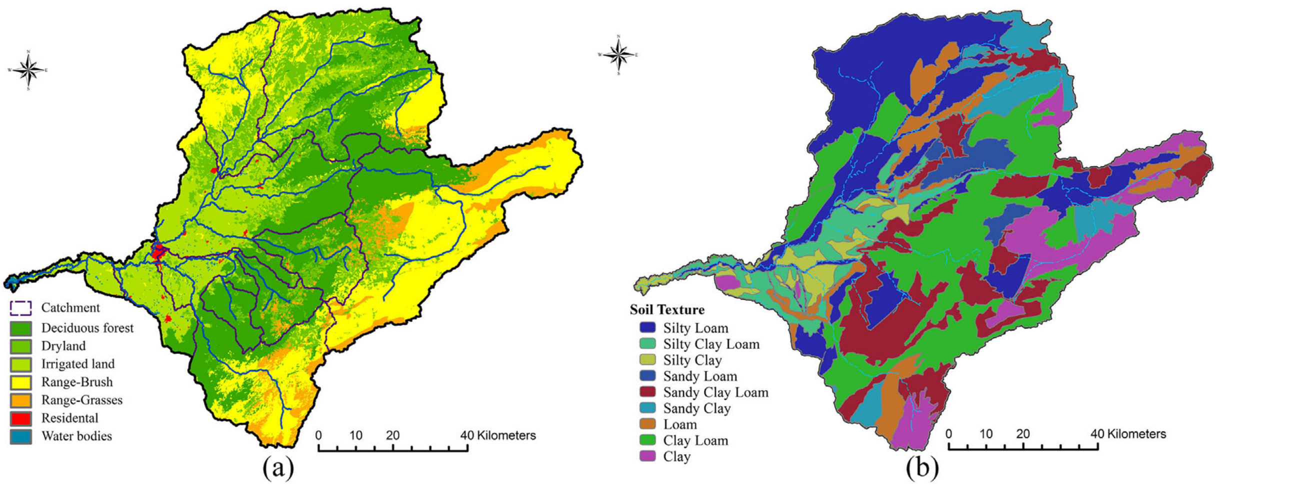

Figure 2. Land use map (a) and soil texture class map (b) of Gorganroud watershed.

using a 90 m digital elevation model (http://srtm.csi.cgiar.org). The slope map was derived from the digital elevation model and classified into five classes. Finally, through defining a threshold area of 5000 ha, the watershed was discretized into 554 HRUs and 79 sub-basins.

2.4 Calibration and sensitivity analysis

The watershed model was previously calibrated and validated for the stream flow and sediment yield, Azari et al. [48]. In this study, the watershed model was calibrated and validated using at least 20 years of monthly data from six hydrometric stations to increase the reliability of the watershed model and to depict climate change impacts assessment. Calibration and validation were conducted using the sequential uncertainty fitting algorithm (SUFI-2) [49]. For quantifying the quality of calibration and uncertainty performance, *P*-factor and *R*-factor indices were used in SWAT Calibration and Uncertainty Programs (SWAT-CUPs). Maximum value for the *P*-factor which is the percentage of data bracketed by the 95% prediction uncertainty (95 PPU) band is 100%. The *R*-factor is the ratio of the average distance between the upper and lower 95PPU to the standard deviation of the measured variable. Providing the best available input dataset from local sources and a physically meaningful range of parameters ensured unbiased parameter adjustment and representation of the actual physical processes [46, 47]. The performance of the model was evaluated by the Nash-Sutcliffe efficiency (NSE) [50], and the coefficient of determination (R^2). The Nash-Sutcliffe efficiency can range from negative infinity to 1, with 1 denoting a perfect fit.

Monthly calibration and validation results for the stream flow and sediment yield at the main outlet (Ghazaghli station) are presented in Table 1. SWAT performance was considered very good in simulating stream flow and satisfactory for sediment yield based on criteria proposed by Moriasi et al. [51], and fell within the ranges of other SWAT studies listed in Gassman et al. [45].

2.5 Future climate data

In this study, climate simulations were used statistically downscaled by the Climatic Research Unit, University of East Anglia [52]. The three global climate models used in the present study include the Canadian Global Climate Model version 2 (CGCM2) from the Canadian Center for Climate Modeling and Analysis, Hadley Centre Coupled Model version 3(HadCM3) from the Hadley Centre for Climate Prediction and Research, and Commonwealth Scientific and Industrial Research Organization GCM mark 2 (SCIRO2) from the Australia's Commonwealth Scientific and Industrial Research Organization. Projected CO_2 concentrations for three emission scenarios include the highest (A1FI scenario: 970 ppm by 2100), lowest (B1 scenario: 550 ppm by 2100) and plausible (A2 scenario: 845 ppm by 2100) chosen for present study. Monthly maximum and minimum temperature and precipitation on a 0.5° grid are available for globe from 2001 to 2100. Emission scenarios and three GCMs were used to cover a large amount of uncertainty regarding the climate change in future, published by the Inter-governmental Panel on Climate Change, IPCC.

In the present study, the climate change scenarios were generated using downscaled average monthly precipitation and monthly mean temperature data. Observed monthly precipitation and temperatures from meteorological stations of the study area for 1971–2000 were used for comparison of the downscaled climate models. GCMs data on the coarse resolution grids were spatially interpolated to each station using the inverse distance weighted, IDW, method using four native neighbors [53] and Eq. (3).

$$S_i = \sum_{k=1}^{4}\left[\frac{1}{d_{i,k}^{m}}\left(\sum_{j=1}^{4}\frac{1}{d_{i,j}^{m}}\right)^{-1} p_k\right] \tag{3}$$

where S_i is the estimated climatic variable at a station i, P_k is the GCM projection at the cell k, $d_{i,k}$ is the distance from station i to the center of GCM cell k, and $m=3$. The change factor, CF, method [41, 54] was used to generate climate change scenarios for 2040–2069. In the change factor method the ratio between GCMs simulations of monthly precipitation for future and current climate ($P_{CM,fut,m}/P_{CM,ref,\ m}$) is used as a correction factor for observed daily precipitation ($P_{obs,d}$) to obtain adjusted daily precipitation for the future ($P_{adj,fut,d}$) (Eq. (4)). Also adjusted daily temperature for future($P_{adj,fut,d}$) was obtained by adding the difference between monthly temperature projected by GCMs for future and current

Table 1. Monthly model calibration and validation statistics for stream flow and sediment yield

Variable	Calibration				Validation			
	P-factor	R-factor	R^2	NSE	P-factor	R-factor	R^2	NSE
Flow	0.77	1.17	0.78	0.77	0.76	1.17	0.71	0.70
Sediment yield	0.62	0.33	0.64	0.61	0.68	0.43	0.55	0.51

climate($T_{CM,fut,m}$ $T_{CM,ref,m}$) to observe daily temperature ($T_{obs,d}$) (Eq. (5)).

$$P_{adj,fut,d} = P_{obs,d} + \left(\frac{\overline{P}_{CM,fut,m}}{\overline{P}_{CM,ref,m}}\right) \quad (4)$$

$$T_{adj,fut,d} = T_{obs,d} + \left(\overline{T}_{CM,fut,m} - \overline{T}_{CM,ref,m}\right) \quad (5)$$

All climate change scenarios were run for a 30-year time period (2040–2069). Each climate change component (temperature, and precipitation) was changed for the entire 30-year time period. The data were then summarized by annual and monthly averages based on the present-day simulation.

2.6 Soil and water conservation practices in SWAT

Three soil and water conservation practices were implemented within SWAT for each climate scenario for the baseline and the future. The soil and water conservation practices scenarios considered in this study were selected based on the history of past practices implemented in the Gorganroud watershed [42]. The practices selected for representation were: Range management practices including grazing management and range planting, terrace construction in agricultural land, and porous gully plugs in streams (Table 2). Each management measure implemented in SWAT using the methods and values were acquired from the literature [35, 41, 55, 56].

Range management practices via grazing management and range planting is effectively managing the harvest of vegetation on grazing lands with grazing animals in such a way that adequate ground cover is always maintained, thereby minimizing erosion. Based on range management studies in watershed determination of optimal usage and minimum plant biomass for grazing were determined. Grazing management was represented in SWAT by the reduction of the harvest index of range plants (similar to Tuppad and Srinivasan [55, 56]). Range planting establishes adapted perennial vegetation on areas where vegetation cover on the ground is poor and/or is below the acceptable level for natural reseeding to occur. The range planting in this study was simulated by adjustment of CN values [55].

Terraces are broad earthen embankments or channels constructed across the slope of a field to intercept runoff water and control erosion [55].

Terraces are earthen embankments or channels constructed across the slope to Intercept runoff water and control soil erosion. The effect of terraces was simulated in SWAT by adjustment of CN2 and conservation support practice factor (USLE_P) on agricultural lands.

Porous gully plugs are generally installed on the ephemeral gullies for reducing the velocity of concentrated flow thereby reducing the erosive power of flowing water and facilitating sediment settling [57, 58]. The gully plugs were simulated by modifying the Manning's roughness coefficient, CH_N1, for tributary channels instead of the main channel as in the case of stream bank stabilization [41].

3 Results and discussion

3.1 Impact of climate change on water resources

Average monthly changes in maximum and minimum temperature show that the increase in temperature in 2040–2069 for maximum temperatures in A1F1, A2, and B1 emission scenarios are 3.3, 2.9, and 2.2°C, while for minimum temperatures are 3.1, 2.1, and 2.7°C, respectively (Fig. 3). Changes in mean monthly T_{min} ranged from 0.7 to 4.9°C with the highest increases from May to June. The mean monthly T_{max} showed future increases of 0.7–4.3°C, with the highest increases in August, September and May and lowest increase in November. Overall, projections by GCMs show an increase in temperature over the entire basin for the period 2040–2069. Average annual precipitation increases ranged from 3.3 to 6.5%. Relative changes in monthly precipitation for emission scenarios during the period 2040–2069 are presented in Fig. 4. However, the relative changes were not evenly distributed throughout the year. Most mean monthly precipitation values decreased in spring (May–June), August and December; although some precipitation increase occurred in March. Abbaspour et al. [16] studied the effect of climate change on the water resources in Iran. They reported an increase in the precipitation in the northern parts of Iran. Therefore, the results are consistent with the finding of Abbaspour et al. [16].

Climate simulations for nine scenarios (three GCMs for three emission scenarios) were applied to SWAT, one at a time and results

Table 2. Conservation practices and their extend in the present study

Soil and water conservation practice	Land use	Extent	Number of Subbasin
Range management	Poor range	1301.2 km^2	18
Terrace construction	Agricultural land with suitable slope	790.1 km^2	26
Porous gully plugs	Ephemeral gullies	660 km	28

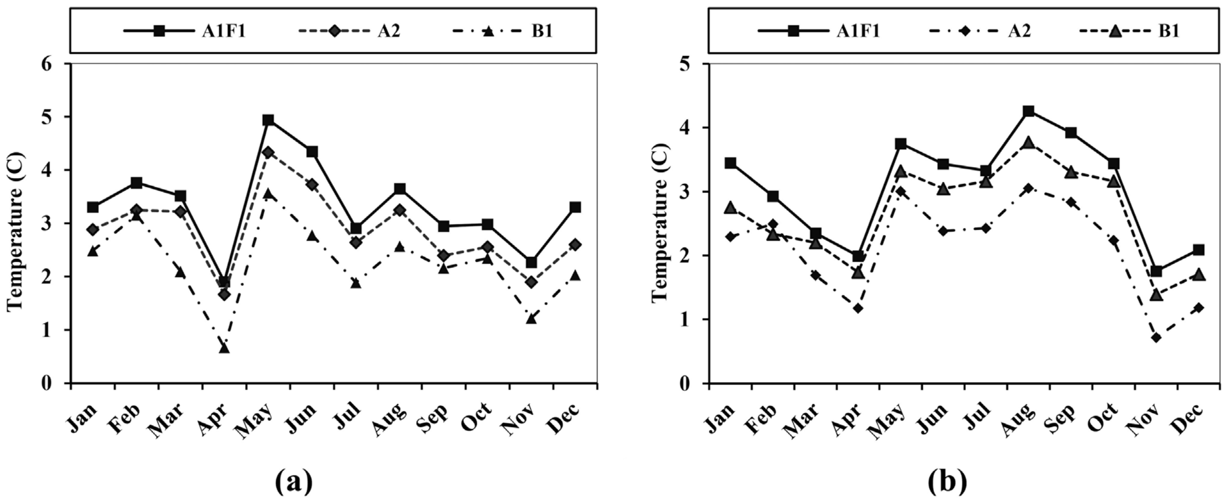

Figure 3. Predicted changes in maximum (a) and minimum (b) temperature during the period 2040–2069 for emission scenarios.

were compared with historical periods' data. Average annual stream flow and sediment yield generally increased under future climate emission scenarios with different temporal patterns on a monthly scale. Changes in mean annual stream flow ranged from −14.2% (scenario A2 of CSIRO2 (Commonwealth Scientific and Industrial Research Organization Gcm Mark 2)) to 21.8% (scenario B1 of HadCM3) for the period 2040–2069 (Fig. 5a). Average percent change in simulated annual stream flow is 5.8, 2.8, and 9.5% for A1F1, A2, and B1emission scenarios, respectively. At the monthly time step, the increase in stream flow is more noticeable in March and April and the decrease is more pronounced from July to September (Fig. 5a). Climate change impacts on monthly precipitation show that values have increased in March and partially in April up to 24.4% for the A1F1 scenario (Fig. 4). With respect to participation of subsurface flow and underground water in stream discharge, significant increase in discharge has been projected for March and April (Fig. 5a). The investigation also shows that the climate change will increase heavy rainfall in the watershed; the number of such days in March and April with >50 mm will increase by 25 and 30% in 2040–2069. This may cause more surface runoff and floods in watershed. Abbaspour et al. [16] also reported that climate change may increase frequency and intense floods in wet regions of Iran. The increase of temperature and change in precipitation form from snow to rainfall is another reason for the increase in discharge as compared to precipitation. An increase of stream flow in the wet season and a decrease in the dry season was concluded by Rahman et al. [59], Yu and Wang [60], Phan et al. [26] and Shrestha et al. [29] in different regions. An increase in runoff and water yield in spring and a noticeable decrease in summer were reported by Chang and Jung [20] and Wu et al. [19].

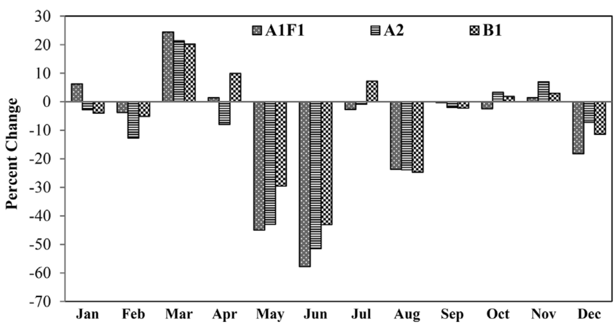

Figure 4. Predicted average relative changes in monthly precipitation during 2040–2069 for emission scenarios.

Average annual sediment yield also generally increased under future climate emission scenarios (Table 3). Generally, the climate change impacts in the increase of sediment for the A1F1, A2 and B1 emission scenarios in the period 2040–2069 are 47.7, 35.9, and 44.5%, respectively. The projected sediment yield is consistent with those reported by Favis-Mortlock and Guerra [3], Perazzoli et al. [61] and Nearing et al. [6] who simulated sediment yield using the SWAT model.

The highest increase in monthly sediment yield was projected for March by 149.2, 129.4 and 121.9% for A1F1, A2, and B1 emission scenarios. In current climate nearly 75% of the sediment yield of the watershed study occurred in January to May and 20% of this happened in March. Therefore, any increase in rainfall in these months might have a huge impact on sediment yield. By taking into account that climate change will accelerate frequency and magnitude of floods in the north of Iran, it is expected that the increase in sediment yield will be more than the stream flow which has also been reported by Zhang et al. [62] and Nunes et al. [7]. An increase of heavy rainfall, mostly in the wet season in future, can accelerate soil erosion and sediment yield. In addition, an increase of temperature in winter and a shift in winter precipitation from snow to more erosive rainfall is another reason for the increase of sediment yield. Overall, predictions of model show that sediment yield will increase for all months except May, June, August and December (Fig. 5b). A decrease in sediment yield during summer may be related to the changes in antecedent soil water content during rainfall events under future conditions; furthermore, increases in evapotranspiration and increase in crop biomass productivity during the months of May and June can reduce soil water content. The importance of antecedent soil moisture on erosion and sediment yield has been previously reported by Fitzjohn et al. [63]. Therefore, the results are consistent with the finding of both Nunes et al. [7] in two Mediterranean watersheds, and Mukundan et al. [28] in a Cannonsville watershed in New York State. Comparison of climate change impacts on sediment yield and

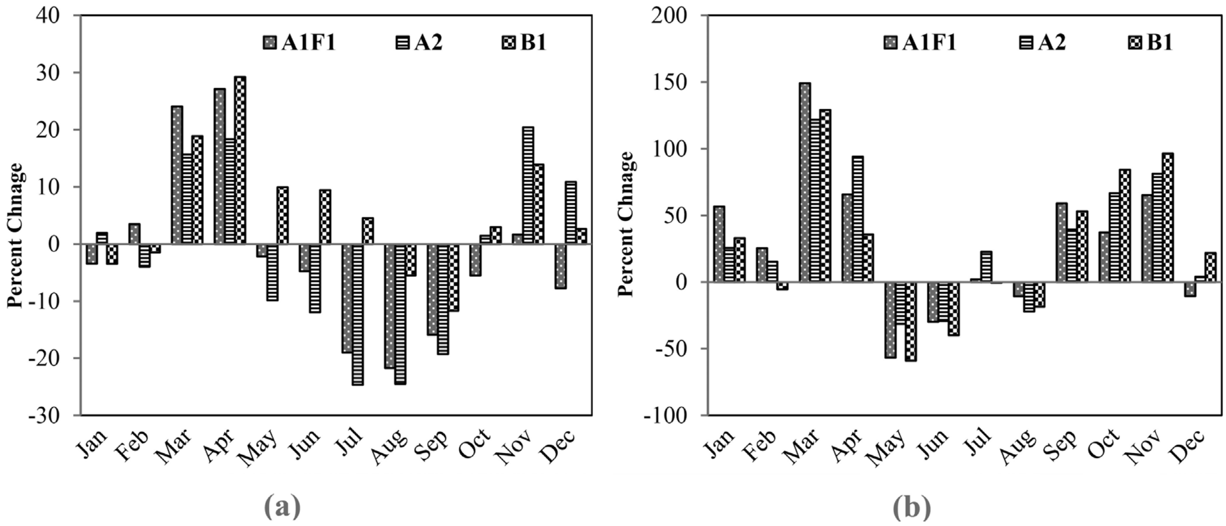

Figure 5. Predicted relative changes in stream flow (a) and sediment yield (b) by different emission scenarios for the period 2040–2069.

stream flow indicated that sediment yield change is more than the stream flow and this was in line with other studies [7, 10, 40, 62]. This result is due to the response of soil erosion to be nonlinear with rainfall [2] and the relation between stream flow and suspended sediment yield is usually defined as a power function [64]. In addition, the changes of sediment yield and discharge in response to climate change do not always happen in the same direction [29]. Although there is a decrease in rainfall, the sediment still increases, which might be due to the increase in temperature. Increased temperature may aggravate the soil erosion rate and, consequently, increase sediment flux through its influence on vegetation and weathering.

3.2 Climate change Impact with implementation of soil and water conservation practices

Three soil and water conservation practices and a baseline condition were introduced to SWAT for each climate change scenario to develop 27 unique conservation practices/climate change emission scenarios. The SWAT model was run under the three emission scenarios (A1F1, A2 and B1) to quantify the effectiveness of conservation practices on sediment yield in mitigation climate change. Predicted relative changes in suspended sediment yield of sub-basins with implementation of soil and water conservation practices are presented in Fig. 6 under plausible emission scenario (A2) for 2040–2069. As shown in Fig. 6a–c soil and water conservation practices were proposed at their maximum possible level in all HRUs of various sub-basins. However, based on the conditions which were defined for each practice, it is applicable in limited sub-basins (Table 2). For example range and grazing management in range lands was implemented in poor range with an area of about 1301 km^2, and coverage of about 50% of entire watershed ranges. Study results revealed that the effectiveness of conservation practices in the reduction of suspended sediment yield may vary under future climate change scenarios. In general, the effectiveness of soil and water conservation practices was evaluated at two scales: Watershed and sub-basin. The watershed scale represents results from the watershed at the main outlet (Ghazaghli station), while the sub-basin scale represents the aggregated results of all HRUs in the sub-basin (Fig. 6a–c). In other words, the sub-basin scale represents the results for the overland load whereas the watershed scale represents the results for overland transport and routing through the stream network.

3.2.1 Effectiveness of range management practices

Simulation results for the range management practices in the baseline showed a 2.8% decrease of suspended sediment yield in the main outlet (Fig. 7). Climate change impacts driven by the three GCMs indicated an average increase of sediment with 47.7, 35.9, and 44.5% in A1F1, A2, and B1 emission scenarios, separately, whereas, after implementation of range management practices in the watershed, the impacts were 43.6, 34.8, and 41.5% for the emission

Table 3. Predicted relative changes in monthly sediment yield for the period 2040–2069

Model//Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
CGCM2//A1F1	41.4	13.7	286.3	156.0	−48.9	−0.8	−24.2	43.1	38.1	42.9	68.6	6.2	83.9
HadCM3//A1F1	106.7	84.9	49.9	−29.5	−70.5	−49.0	29.0	−39.8	102.4	28.8	1.6	−66.0	25.9
CSIRO2//A1F1	21.8	−22.0	111.5	71.0	−50.6	−39.6	1.3	−35.2	36.7	40.5	125.7	28.4	33.3
CGCM2//A2	31.0	5.2	226.7	141.1	−51.7	−32.6	−29.6	9.3	53.4	32.2	30.6	−4.8	62.9
HadCM3//A2	67.9	−4.8	106.5	−6.3	−69.8	−41.5	19.8	−35.0	80.3	183.2	213.8	71.8	43.9
CSIRO2//A2	0.4	−16.6	54.4	−27.0	−55.2	−45.2	8.6	−29.6	25.9	37.5	45.3	−1.2	0.9
CGCM2//B1	2.8	30.9	132.0	153.8	−19.0	−26.4	−2.1	5.3	50.1	60.2	23.8	−23.1	48.7
HadCM3//B1	47.4	16.5	125.3	116.4	−19.3	−27.7	65.6	−45.5	43.5	61.4	80.2	21.2	54.7
CSIRO2//B1	27.1	−1.4	108.3	12.2	−55.7	−33.0	5.2	−25.5	25.0	78.6	140.1	14.4	30.0

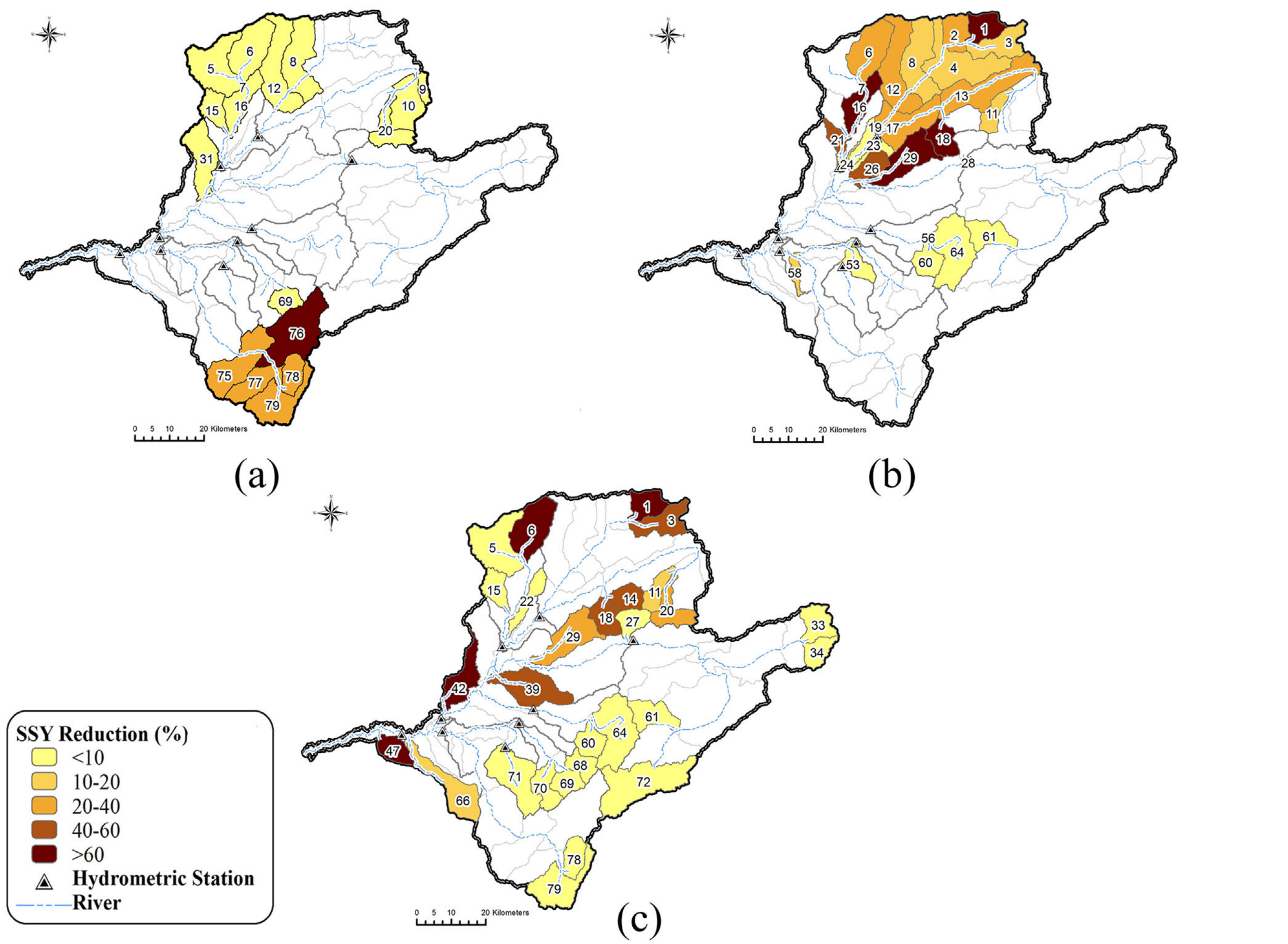

Figure 6. Predicted relative changes in suspended sediment yield with implementation of range management practices (a), terrace construction practice (b) and porous gully plugs practice (c) under A2 emission scenario for 2040–2069.

scenarios. In other words, implementing range management practices in the watershed can reduce the adverse effects of climate changes by 4.1, 1.1, and 3% for the aforementioned models and emission scenarios.

The sub-basins affected by the implementation of range management scenario are shown in Fig. 6a. In this figure, the maximum impact of the range management scenario is observed in sub-basins 75–79. In sub-basin 76 which has the maximum efficiency, the total sub-basin area is implemented by the first scenario. This in turn shows that the efficiency of each scenario mostly depends on the extent of the implementation area in the sub-basin and this is consistent with other studies [10, 37]. Sub-basins 75–79 include rangeland in steep mountain regions higher than the forest. Implementation of range management practices and increase of soil infiltration via range planting and grazing management could decrease erosion and sediment flux. In other sub-basins, the extent of reduction is not high which may be related to climatological and soil factors. Also sub-basins 75–79 are very close to the main outlet and could have more participation in sediment yield of the watershed. Therefore, implementing soil and water conservation could reduce the sediment yield of the watershed.

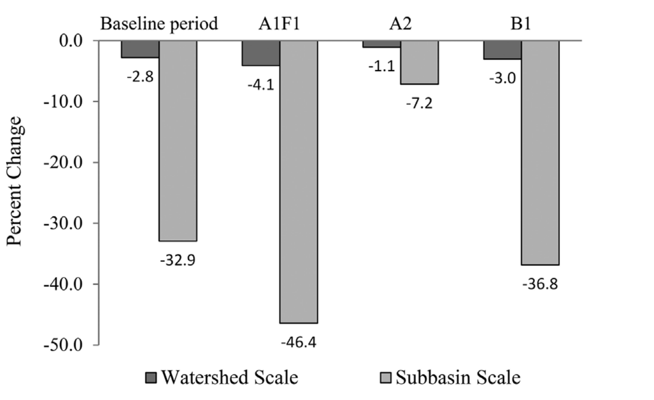

Figure 7. Impacts of range management practices in the reduction of sediment yield in sub-basin and watershed scales for baseline and future climate scenarios.

The results for the sub-basin scale indicated that effectiveness of conservation practices in the reduction of sediment yield is notable. Impacts of range management practices on changes in sediment yield in the sub-basin and watershed scales are compared in Fig. 7. For those sub-basins under range management practices, a 33% decrease was observed in sediment yield for the baseline. In climate change conditions, implementation of this scenario caused a decrease by 46.4, 7.2, and 36.8% for three emission scenarios (A1F1, A2, and B1).

3.2.2 Effectiveness of terrace construction practice

In the second conservation practice, terrace construction in agricultural land that has been suggested for agricultural lands, a 4.6% decrease was observed in the suspended sediment yield in the main outlet for the baseline period (Fig. 8), whereas with terrace construction, the impacts resulted in a decrease of 7.2, 6.9, and 7.1% for A1F1, A2, and B1 emission scenarios, separately. These reductions for sub-basins for terrace construction in agricultural land were 21.6, 20.4, and 21.2% for the aforementioned emission scenarios.

Terrace construction which was proposed for agricultural steep lands is located in the northern part of the watershed (Fig. 6b). The impact of this practice can vary based on extent of implementation area, and the amount of soil erosion and sediment of the sub-basin. Therefore, more than 60% difference could be observed before and after implementation.

Another important factor on the efficiency of the BMP scenarios is the number of HRUs of each sub-basin, which is suitable for the scenario. For example, nearly 41% of sub-basin number one was implemented by the second scenario and as a result its efficiency is very high. Bosch et al. [10] showed that enhanced BMP implementation could compensate for the climate-driven increases in yields. However, the BMP implementation area along with climatological conditions and the extent of sediment yield can determine the efficiency of each BMP.

3.2.3 Effectiveness of porous gully plugs practice

Porous gully plugs installed on the ephemeral gullies, showed a decrease of 5.9% of sediment yield in the main outlet in the baseline scenario (Fig. 9). After the implementation of porous gully plugs on the ephemeral gullies, impacts of climate change in sediment yield for the emission scenarios decreased by 6.9, 7.2, and 7.2% for A1F1, A2, and B1 emission scenarios. The average of suspended sediment yield in sub-basins for porous gully plugs installed on the ephemeral gullies was 5 ton/ha per year. Implementation of porous gully plugs in sub-basins has caused a decrease of 18.3% in sediment yield for the baseline. While the projection of three emission scenarios (A1F1, A2, and B1) showed an increase of suspended sediment yield with 53.7, 48.5, and 54.4%, the porous gully plugs as an mitigation practice decreased sediment yield by 23.4, 23.5, and 24.1% for the three emission scenarios in sub-basins.

The third scenario is applicable to most parts of the watershed (Fig. 6c). It is implemented in 28 sub-basins. According to Fig. 6c, the

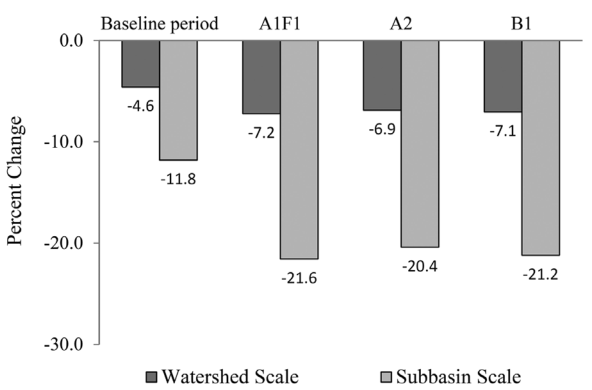

Figure 8. Impacts of terrace construction practice in reduction of sediment yield in sub-basin and watershed scales for baseline and future climate scenarios.

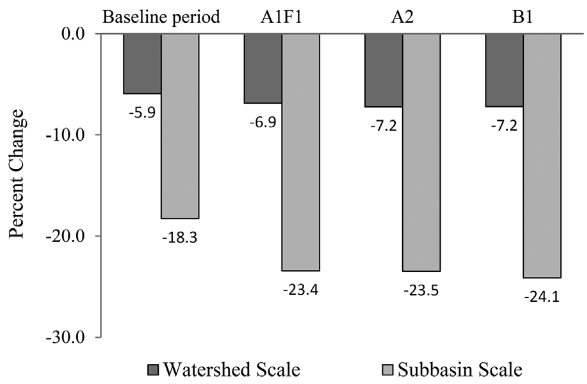

Figure 9. Impacts of porous gully plugs practice in reduction of sediment yield in sub-basin and watershed scales for baseline and future climate scenarios

efficiency of this scenario in the northern part of the watershed is high which is higher than the other parts. The extent of efficiency depends on the amount of soil erosion and length of river reach which is suitable for the third scenario. The impact of the third scenario is <10% in the southern part of the watershed which encompasses forest and good vegetation cover. In sub-basin numbers 60, 68, and 69 the length of implantation reach has been short and therefore has had little impact on sediment yield reduction. In sub-basins 29 and 39, the impact of this scenario is notable due to scarcity of vegetation cover and erodible geological formations such as losses which in turn cause soil erosion.

It can be concluded from the present results that the efficiency of conservation practices is low in the main outlet, but it is notable in the sub-basin scale. Sub-basin and watershed scale reductions have a similar reduction pattern which was reported by Woznicki and Nejadhashemi [40] in Tuttle Creek Lake watershed. In addition, the effectiveness of the recommended conservation practices on the sub-basin scale is more than the watershed scale which is in line with Tuppad et al. [57] and Woznicki et al. [37]. Range management practices are less effective for sediment yield reduction at the watershed scale which may be related to channel processes such as deposition [40]. In the watershed scale porous gully plugs were the most effective practices in the reduction of sediment yield. In a study by Woznicki et al. [37] in Tuttle Creek Lake, similar results were reported which may point to a connection regarding how the porous gully plugs are presented within SWAT. The percentage of reduction in sediment yield is more dependent on implemented area and type of practices; however, this percentage of reduction in suspended sediment yield is close to some studies as,for example, Betrie et al. [65].

Under future climate, range management practices were the most effective practice in sediment decrease at the sub-basin scale and porous gully plugs and terrace construction were the most effective practices at the watershed scale. High effectiveness of range management practices under climate change is similar to the findings of Woznicki et al. [37] and van Liew et al. [39], in which conversion of cropland to pastures was found to be the most effective of BMPs.

The study results indicated that effectiveness of conservation practices in sediment reduction will increase for both scales except for range management practices in the A2 scenario. Variability in sediment reduction for the conservation practices is noteworthy. Terrace construction and porous gully plugs have the lowest variability in percent reduction (Figs. 8 and 9); whereas, range management practices have the greatest variability in percent reduction under future climate (Fig. 7).

The study results clearly illustrate that the effectiveness of current conservation practices will change in the future for both sub-basin and watershed scales. The results indicate that aforementioned soil and water conservation practices will be more effective at reducing sediment yields under anticipated future climates. Woznicki et al. [37] reported in Tuttle Creek Lake that contour farming and terraces proved to be noticeable increases in reduction and porous gully plugs revealed no important change in performance under any scenario. Findings by van Liew et al. [39] in shell and Logan creek watersheds in Nebraska also indicated that effectiveness of agricultural BMPs in reduction of sediment yield will increase under climate change.

The results were based on procedures applied in studies investigating the spatial and temporal changes of soil erosion and sediment yield which encompasses the model calibration and validation in a few hydrometric stations within the watershed [10, 14, 20, 29, 37, 40, 58, 66]. However, we believe the main drawback for all such studies lies in the fact that the final model cannot simulate inter-HRUs or sub-basins properly. In the present research, the model was calibrated and validated using at least 20 years of monthly data from six hydrometric stations within the watershed. Therefore, in order to increase the reliability of the watershed model, 20 years' worth of data was used instead of a shorter time span to depict climate change impacts' assessment. On the other hand, the performance of the present model for sediment yield prediction does not stray very far from similar studies [67–69]. Nevertheless the performance of the model for the prediction of sediments in sub-basins is not as good as the main outlet which was elaborated in Azari et al. [48]. This can possibly be attributed to the uncertainty in sediment yield methods (the MUSLE model) used in SWAT which was developed to estimate event-based soil erosion from agricultural fields and small watersheds. Similar under-prediction of sediment loads by SWAT has also been described in a few other studies [70–72]. However, the difference between the results at sub-basin and the watershed scales may partially be related to the different performance of the model at two scales.

4 Concluding remarks

One factor which greatly hampers the selection of the best conservation practices for adaptation/mitigation to climate change impacts on soil and water resources is that past effective conservation practices may no longer be adequate under future climate conditions. Hence, assessing the effectiveness of current conservation practices under changed climatic conditions that are assumed to prevail in the future is of utmost importance [6, 34, 36]. Much research has been conducted to establish the potential need for additional and/or more effective conservation practices to provide adequate protection; however, these efforts are disrupted by sizable uncertainties in the projected future climate for which conservation practices are sought [10]. This study evaluated the effectiveness of current soil and water conservation practices with respect to sediment yield from the sub-basin and watershed under various climate change scenarios. The SWAT model in combination with the SWAT-CUP package was used for calibration, validation and uncertainty analysis. Future climate scenarios for the period of 2040–2069 were generated from three GCMs (CGCM2, HadCM3, and SCIRO2) for emission scenarios A1F1, A2, and B1, which were further downscaled using the meteorological data. The study results for the period 2040–2069 compared with that of historical period (base line) showed an increase of 5.8, 2.8, and 9.5% in annual stream flow and an increase of 47.7, 35.9, and 44.5% in sediment yield for emission scenarios A1F1, A2, and B1, respectively. This indicates that the impact of climate changes on sediment yield is greater than on stream flow. Monthly variation shows an increase in sediment yield and stream flow in wet season and a decrease in summer.

Implementation of the proposed conservation practices in the hydrological model of the watershed showed decreases of 1.1, 6.9, and 7.2% in sediment yield for the A2 scenario at the watershed scale, whereas in the sub-basin scale, these were 7.2, 20.4, and 23.5%. Range management practices were the most effective practice in sediment decrease at the sub-basin scale and porous gully plugs and terrace construction are the most effective practices at the watershed scale. The study results indicated that effectiveness of conservation practices in sediment reduction will increase for both scales. Porous gully plugs and terrace construction have the lowest variability and range management practices have the greatest variability in percent reduction under future climate. The study results also clearly show that effectiveness of current conservation practices will change in the future for both sub-basin and watershed scales. The results indicate that soil and water conservation practices will be more effective at reducing sediment yields under anticipated future climates; however, the implementation of any conservation practice by itself, as defined in the present study, was not sufficient to compensate for climate change-driven increases in sediment yield. In order to make the results more practical, the results were presented in the sub-basins as shown in Fig. 6a–c. According to personal communications with local managers, also the past literature [42], we think it is applicable for local managers to implement the proper scenario in sub-basins with high priority. This study provides valuable information for watershed managers and decision makers regarding selection of soil and water conservation plans in current and future climates. Use of additional climate models and soil and water conservation practices which were not used in this study is recommended for future research.

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