Shahrood University of Technology

Journal of Hydraulic and Water Engineering (JHWE)

Journal homepage: https://jhwe.shahroodut.ac.ir

Iranian Hydraulic Association (IHA)

The capability of the SWAT model in simulating paired benchmark catchments (Case study: Dehgin Watershed)

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Article Info

Article history:

Received 12 June 2026
Received in revised form 3 July 2026
Accepted 6 July 2026
Published online 18 July 2026

DOI:
10.22044/jhwe.2026.17833.1091

Keywords
Paired catchments
Manual calibration
SWAT Model
Check dams
Sediment

Abstract

Quantitatively assessing the effects of watershed management on hydrological response and sediment yield remains challenging due to the lack of natural control catchments. This study employed a paired catchment framework: a natural control catchment and a treatment catchment with several check dams. Flow and sediment transport were modeled using the semi-distributed SWAT model. Manual calibration was performed based on monthly discharge and sediment data. In the control catchment, SWAT showed high accuracy for streamflow (calibration: R^2=0.86, NSE=0.80; validation: R^2=0.92, NSE=0.88). The treatment catchment exhibited weaker performance (calibration: R^2=0.78, NSE=0.65 – good; validation: R^2=0.80, NSE=0.58 – satisfactory) due to flow regime disturbance by check dams. For sediment, the control catchment showed moderate accuracy (calibration: R^2=0.73, NSE=0.69; validation: R^2=0.65, NSE=0.59). Interestingly, the treatment catchment performed better in sediment simulation (calibration: R^2=0.83, NSE=0.71; validation: R^2=0.85, NSE=0.65), attributed to sediment trapping behind dams. The reduced model efficiency in streamflow simulation for the treatment catchment (NSE decrease from 0.80 to 0.58) reveals a key limitation of SWAT in representing hydrological effects of small check dams. Conversely, sediment simulation was more successful due to statistical smoothing. These findings highlight the need to revise parameterization of small check dams in semi-distributed models or adopt hybrid approaches.

1. Introduction

Having information about watershed resources is essential for both short-term and long-term planning. This crucial objective can only be achieved through the establishment and operation of representative catchments within homogeneous regions. Since representative catchments are established and operated in areas with homogeneous hydroclimatic, hydroedaphic, and hydroecological conditions, the results obtained from them can be generalized to such regions. Accordingly, most developed and developing countries around the

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world have selected watersheds as their planning units and pursue all their sustainable development programs within watershed boundaries. The network of representative and paired catchments has been established by the Natural Resources and Watershed Management Organization of Iran with the aim of monitoring and recording accurate spatial data on climatic parameters, erosion and sediment, vegetation cover, soil, and groundwater. These stations have provided a suitable platform for scientific and knowledge-based planning for the management of the country's watersheds and for conducting applied research needed at the national level. Each of the aforementioned representative catchments comprises a pair of treatment and control catchments. They have been established with the objectives of continuously recording climatic factors and spatial data, as well as providing accurate regional statistics and information on meteorological, hydrometric, erosion and sediment, botanical, and groundwater parameters, thereby enabling the monitoring of indicators within the relevant climatic watersheds. Additional objectives for establishing these stations include planning and implementing watershed management patterns, conducting technical, managerial, and socio-economic evaluations, monitoring the implemented patterns, providing extension and educational models for watershed management activities, and laying the groundwork for applied research. Beyond serving as pilot sites for extension and education, these stations function as spatial databases and watershed information banks, thus providing a suitable platform for conducting applied research needed at the national level. In other words, paired catchments are a type of research catchment used to accelerate scientific investigations and may be located within a representative catchment. The procedure is as follows: within one of the sub-catchments, two upstream catchments of two streams are selected that are as similar as possible in terms of area, topography, geology, vegetation cover, soil, slope, lithology, erosion, climate, and other relevant factors. In one of the catchments, natural conditions remain unchanged, and it serves as the control catchment. In the other catchment, changes are introduced through watershed management methods and techniques, and their effects are studied; this is referred to as the treatment catchment (Kazemzadeh, 2018). In order to manage watersheds and prevent inconsistencies among designed measures at the basin scale, simulating the target watershed requires a model capable of handling large volumes of data, including precipitation, topography, watershed boundaries, soil and subsurface layer characteristics, land use and vegetation cover, runoff conveyance systems, existing management structures, and qualitative data on water and groundwater levels (Kavianpour et al., 2011). Simulating paired representative catchments is crucial for predicting watershed behavior, understanding various components of the hydrological and sediment cycles, and planning for the protection of water and soil resources. The SWAT model is a comprehensive, semi-distributed, watershed-scale model developed by the United States Department of Agriculture's Agricultural Research Service (USDA-ARS). This model is designed to simulate the movement of water, sediment, and agricultural chemical pollutants across complex and large watersheds with varying soil types, land uses, and management conditions over long time periods (Neitsch et al., 2011; Memarian et al., 2014). Despite the comprehensiveness of this model and its process-based framework, any model requires calibration and evaluation prior to application. Real-world statistics and information can represent the actual behavior of a watershed. In the dryland conditions of Iran, the lack of monitoring data represents a major limitation. Therefore, the availability of paired and representative catchments equipped with hydrometric and climatological data can be highly suitable for the localization and practical application of models. Accordingly, the most important objectives of the current research are: determining the feasibility of implementing the

SWAT model under arid climatic conditions for the purpose of simulating and calibrating a paired representative catchment, and subsequently applying it to a larger watershed. Lyafoo et al. (2024) modeled erosion and sediment and simulated the effects of conservation measures in the Chehel-Chai watershed, Golestan Province, using the SWAT model. In this study, to ensure model conformity with reality, the simulated and observed sediment loads at the watershed outlet were compared. Sensitive parameters related to surface erosion were calibrated. The Nash–Sutcliffe efficiency (NSE) and R^2 coefficient were used for model calibration, yielding monthly sediment values of 0.48 and 0.59, respectively, indicating good model performance in sediment simulation. Spatial distribution of erosion amounts revealed that critical sub-watersheds were located in agricultural areas with steep slopes. Finally, the effects of proposed conservation measures on watershed sediment yield were investigated. The proposed management measures included alfalfa cultivation, agroforestry (integration of cropping and tree planting or cultivation of medicinal plants such as saffron), establishment of productive orchards, and a combination of all three measures, selected through consultation with local watershed residents and experts. The results showed that among the conservation measures, the combined measure had the best performance in reducing sediment (approximately 30% reduction).

Ahmadi et al. (2023) conducted a study evaluating the effects of water and soil conservation measures in a part of the Tajan watershed, Sari, Iran. This research was carried out in three sub-watersheds—Langar-e Yek, Margav, and Sadat Mahalleh—within the Tajan watershed to assess the impacts of water and soil conservation measures. In the Langar-e Yek sub-watershed, the effectiveness of watershed management measures on erosion and sediment factors, land use change, peak discharge and flood volume, economic issues of local residents, and vegetation cover changes before and after the implementation of watershed projects was investigated. In the Margav sub-watershed, soil erosion was estimated using the RUSLE model, followed by land use change and land conservation scenarios. Subsequently, in the Sadat Mahalleh sub-watershed, runoff and sediment processes were simulated using the SWAT model. The results for the Langar-e Yek watershed showed that the implementation of biological and mechanical measures across the entire watershed reduced erosion and sediment by 17.89% and 25.94%, respectively, increased the dense vegetation cover index (NDVI) by 30%, reduced flood volume by 1,178.18 million cubic meters, and increased the benefit-to-cost ratio for local residents by 1.12. The results from the Margav sub-watershed indicated that the average soil loss using the RUSLE model in agricultural lands, orchards, and degraded forest areas was 25.4 t ha^{-1} yr^{-1}. The Nash–Sutcliffe efficiency (NSE) results for the calibration and validation stages of the runoff simulation process using the SWAT model for the Sadat Mahalleh sub-watershed for the periods 2000–2012 and 2013–2019 were 0.62 and 0.67, respectively, while for the sediment simulation process, they were 0.45 and 0.65, respectively, indicating satisfactory model performance in simulating runoff and sediment processes.

Drini et al. (2023) conducted a study on the hydrological simulation of the Riz Gelleh and Shahr-e Babak watershed using the SWAT model. This research aimed to simulate monthly discharge and sediment yield using the aforementioned model and to identify sub-watersheds critical for specific sediment yield within the Riz Gelleh and Shahr-e Babak watershed, located in western Kerman Province, Iran. The results showed that among four algorithms, the SUFI-2 algorithm yielded the best monthly simulation results, with Nash–Sutcliffe efficiency (NSE) and coefficient of determination (R^2) values of 0.82 and 0.82 during the calibration period, and 0.81 and 0.81 during the validation period, respectively.

Zahedi et al. (2022) conducted a study on the hydrological balance simulation of the Samghan River watershed using the SWAT model and the SUFI-2 algorithm. In this research, the SWAT model, which is a conceptual, semi-distributed watershed-scale model, was used for hydrological simulation of the Samghan watershed. After preparing the data according to the required format, the model was executed. Following sensitivity analysis and the determination of important parameters, model calibration and validation were performed. To reduce uncertainty, various components of the water balance were considered during calibration, and observational data from several measurement stations were used simultaneously. Subsequently, the SUFI-2 algorithm was employed for model calibration and validation. The calibration process was conducted for the period 2007 to 2013, and the validation process for the period 2014 to 2017. To evaluate the simulation results, the coefficient of determination (R^2), weighted correlation coefficient (bR^2), and Nash–Sutcliffe efficiency (NSE) were used. During the calibration stage, the R^2, R^2, and NSE values were 0.74, 0.71, and 0.68, respectively, while during the validation stage, they were 0.69, 0.62, and 0.59, respectively. The indices and graphs obtained from the calibration and validation stages for monthly runoff simulation indicated that the model performed more successfully during the calibration stage. Furthermore, the model was able to accurately determine the timing of peak discharge events.

Given the review of the existing literature, very few studies have been conducted on the simulation of paired representative catchments using the SWAT model, and there is a lack of up-to-date research in this field. The innovative aspects of this study are threefold:

This is among the first studies to apply the SWAT model to a paired catchment in Iran, where both control and treatment catchments are simulated simultaneously within a single modelling framework, providing a direct comparison of hydrological and sedimentological responses with and without watershed management interventions.

The study evaluates the hydrological and sedimentological response to check dam construction in a hyper-arid environment, providing valuable insights into the performance of watershed management structures under extreme climatic conditions, which has rarely been addressed in previous research.

A transparent and reproducible manual calibration protocol is developed and presented in detail, which can serve as a reference for future SWAT applications in data-scarce arid regions where automated calibration tools may not be readily applicable.

Therefore, the primary objective of this study is to investigate the capability of the SWAT model in simulating a paired representative catchment under hyper-arid conditions and to provide a comprehensive evaluation of model performance in both control and treatment catchments.

2. Materials and Methods

2.1. Study area and data

The Dehgin paired representative catchment includes treatment and control catchments with areas of 168.4 ha and 200.5 ha, respectively, located within a representative catchment of 368.9 ha in eastern Hormozgan Province, Iran. Geographically, the catchment lies between 57°11′21″ to 57° 12′ 25″ east longitude and 27° 44′ 25″ to 27° 46′ 04″ north latitude, within the main Masafarabad watershed, which ultimately drains into the Esteghlal Dam in Minab (Figure 1). The perimeter of the Dehgin representative and paired catchment is 23.6 km, with a maximum elevation of 521 m in the highlands and a minimum elevation of 459 m at the outlet. The Dehgin paired catchment is situated in a hilly terrain characterized by low mountains, hills, plateaus, and high terraces. The geological formations in the area predominantly consist of Quaternary alluvial deposits, marl, and limestone formations, which influence soil development and hydrological processes. Soil development is primarily controlled by elevation, slope percentage, and parent material type, with shallow to moderately deep soils dominating the landscape. The natural vegetation is sparse and predominantly consists of drought-resistant shrubs and Acacia oerfota (Forssk.) Schweinf (locally known as Kahour), which is native to the region and plays a critical role in soil conservation. The area is also characterized by high evapotranspiration rates, low soil moisture, and flash floods during intense rainfall events, making it highly susceptible to soil erosion and land degradation.

Based on the Emberger and De Martonne climate classification methods, the climate of the study area is classified as hot dry desert and hot hyper-arid, respectively. The mean annual precipitation is only 186.1 mm, while the mean annual potential evapotranspiration (estimated by the modified Blaney–Criddle method) is 1,837.3 mm. The Aridity Index (AI = P/PET) is calculated as 186.1 / 1,837.3 = 0.10, which falls within the arid to hyper-arid class according to the UNESCO aridity classification (AI < 0.05 = hyper-arid; 0.05–0.20 = arid; 0.20–0.50 = semi-arid). Therefore, the study area is unequivocally classified as hot dry (arid to hyper-arid) climate, and no semi-arid characteristics are observed in this region. The study area has a mean annual temperature of 25.8°C. The highest relative humidity occurs in December, January, and February, while the lowest occurs in July and August. The maximum sunshine hours occur in May, and the minimum in December.

The Dehgin paired catchment is one of twelve representative and paired watersheds established by the Natural Resources and Watershed Management Organization of Iran. These catchments are designed to serve as spatial databases and watershed information banks, providing a suitable platform for conducting applied research and evaluating watershed management operations. The environmental importance of the Dehgin catchment lies in several aspects:

Water scarcity and aridity: Located in one of the driest regions of Iran (Hormozgan Province), the catchment faces extreme water scarcity, with annual precipitation of less than 200 mm and potential evapotranspiration exceeding 1,800 mm. Understanding the hydrological response in such hyper-arid conditions is critical for sustainable water resource management in similar arid regions.

Vulnerability to soil erosion: The region is highly susceptible to soil erosion due to sparse vegetation cover, steep slopes, and intense rainfall events. Soil erosion is one of the most critical environmental problems in Iran, leading to economic losses and land degradation. The Dehgin catchment serves as a natural laboratory for studying erosion processes and evaluating soil conservation measures.

Check dam effectiveness: The presence of paired sub-catchments (control vs. treatment) allows for a direct comparison of hydrological and sedimentological responses with and without watershed management interventions. This provides valuable evidence for the effectiveness of check dams in mitigating runoff and sediment yield, which is essential for informed decision-making in watershed management.

Biodiversity and vegetation: The region supports drought-tolerant plant species such as Acacia oerfota, which are adapted to the harsh climatic conditions. Studies on precipitation storage and vegetation restoration in this area have demonstrated the potential for improving soil moisture and seedling growth, contributing to pasture improvement and afforestation efforts.

Data availability for modeling: The long-term monitoring of climatic, hydrometric, and sediment data in the Dehgin catchment provides an invaluable resource for hydrological modeling and calibration, making it a key site for advancing scientific understanding of watershed processes in arid environments.

The mean annual precipitation of the catchment is 186.1 mm, and the mean annual potential evapotranspiration estimated by the modified Blaney–Criddle method is 1,837.3 mm (adapted from the soil survey reports of the Dehgin Paired Catchment, 2012). The study area has a mean annual temperature of 25.8°C. The highest relative humidity occurs in December, January, and February, while the lowest occurs in July and August. The maximum sunshine hours occur in May, and the minimum in December.

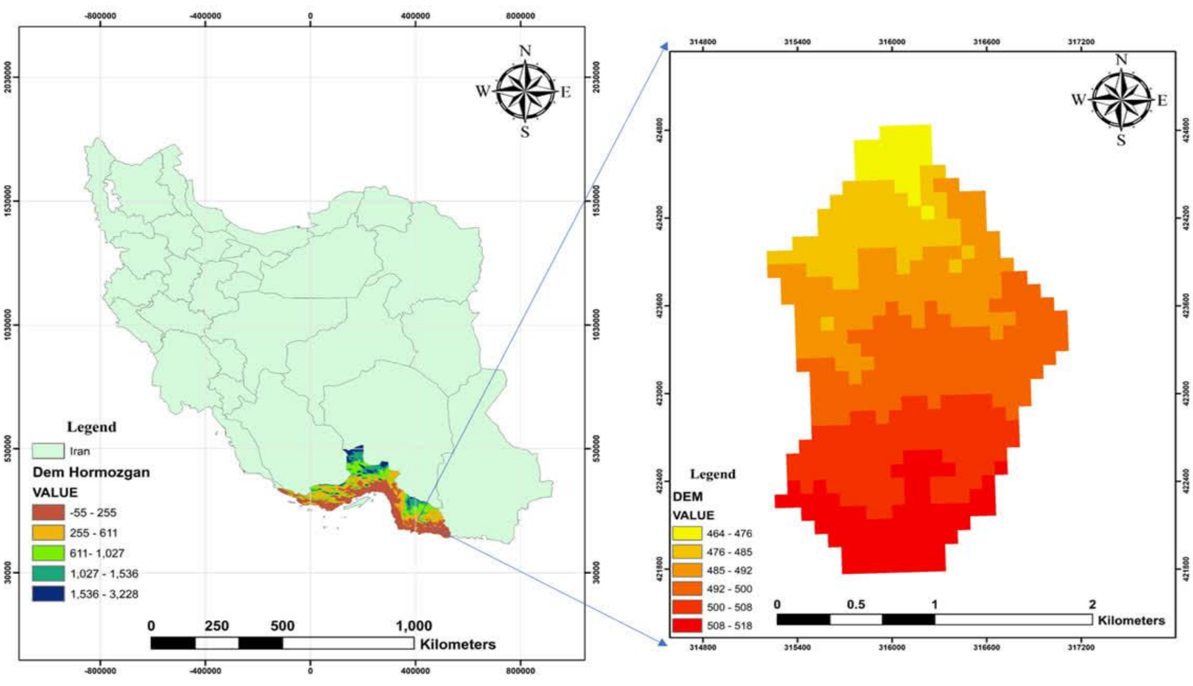


Figure 1. Study area

2.2. SWAT Model

The Soil and Water Assessment Tool (SWAT) is a semi-distributed, continuous-time hydrological model developed to assist water resource managers in evaluating the impacts of various land management practices on river discharge and non-point source pollution (Arnold et al., 1998). Over the past few decades, SWAT has undergone numerous developments and enhancements (Gassman et al., 2007; Arnold et al., 2012). The model typically operates at a daily or monthly time step and is designed for long-term continuous simulation. SWAT can be used for simulating long-term hydrology and climate patterns, and while it performs well for average streamflow analysis, it requires high-resolution temporal input—at least daily—to adequately simulate extreme flood events. For robust climate studies that include both severe droughts and floods, long-term climatic data covering at least 30 years on a daily scale is recommended as input for SWAT simulations (Tan et al., 2020). Model calibration is essential for ensuring the reliability of SWAT outputs, and this is commonly achieved through the SWAT-CUP tool, which incorporates various optimization algorithms (Abbaspour et al., 2007; 2018). Among these, the SUFI-2 (Sequential Uncertainty Fitting Version 2) algorithm is widely used for calibrating SWAT at both daily and monthly time scales. Model performance is typically evaluated using statistical indices such as the coefficient of determination (R^2) and the Nash–Sutcliffe Efficiency (NSE) (Nash et al., 1970). The values of R^2 range from 0 to 1, while NSE ranges from $-\infty$ to 1, with a value of 1 indicating perfect model performance (Zhang et al., 2020).

2.3. Erosion and Sediment

Soil erosion and sediment yield in each Hydrologic Response Unit (HRU) are calculated using the Modified Universal Soil Loss Equation (MUSLE), which was introduced in 1975 (Williams & Singh, 1995). While the USLE uses rainfall as an indicator of erosive energy, MUSLE employs runoff volume for this purpose. SWAT enables the estimation of runoff volume and peak runoff rate, which are used together with the sub-watershed area to compute the erosive energy of runoff. This factor is a function of aboveground biomass, crop residue on the soil surface, and the minimum value of the cover and management factor (C-factor). Sediment routing consists of two simultaneously acting processes: degradation (erosion) and deposition. In the SWAT model, the maximum amount of sediment that can be transported within a channel reach is considered a function of the peak flow velocity.

2.4. Climatic Data

These data include maximum and minimum temperature, daily precipitation, daily maximum and minimum relative humidity, daily maximum and minimum wind speed, and daily solar radiation. This information is entered into the SWAT model either through the weather generator subprogram or directly as measured data (Mengistu et al., 2019).

2.5. Surface Runoff

Surface runoff occurs in a region when the water infiltration rate into the soil is lower than the precipitation rate. When rainfall occurs, runoff is not generated initially due to the high infiltration rate; however, as time passes, the soil becomes saturated, and runoff is generated. To estimate surface runoff and simulate daily, monthly, or annual outflow discharge, two methods are used in this model: the Curve Number (CN) method and the Green–Ampt infiltration equation.

The Curve Number method is an empirical model developed since 1950 by the United States Soil Conservation Service (now NRCS) for estimating surface runoff volumes in watersheds with various land uses and soil types.

2.6. Evapotranspiration

Radiant energy from the sun is the primary driver of evaporation and transpiration from various surfaces. The loss of water from the soil surface is termed evaporation, while the loss from plant surfaces is termed transpiration. The SWAT model provides three methods for calculating evapotranspiration:

Penman–Monteith – requires air temperature, solar radiation, wind speed, and relative humidity.

Priestley–Taylor – requires air temperature, solar radiation, and relative humidity.

Hargreaves – requires only air temperature.

2.7. Model Input Data and Setup

The data required for initiating the modeling process include spatial data and meteorological data. In the present study, first, the spatial input data—including a digital elevation model (DEM) with a spatial resolution of 12.5 m (ALOS PALSAR DEM, acquired from the

Alaska Satellite Facility; https://asf.alaska.edu/), a land use map (indicating land use types), and a soil map (indicating soil types based on hydrological soil group, number of soil layers, soil organic matter, etc.)—were imported into the model . Additionally, the slope layer was classified into four classes (0–5°, 5–10°, 10–20°, and >20°) based on the topography and physiographic characteristics of the study area.

2.8. Step-by-step manual calibration protocol

Although SWAT-CUP was not used in this study, a systematic manual calibration procedure was developed to ensure reproducibility. The following protocol was applied iteratively for both flow and sediment simulations:

1. Initial parameter selection: Based on a comprehensive literature review (Neitsch et al., 2011; Abbaspour et al., 2015), 19 parameters were identified as potentially influential for runoff and sediment yield in semi-arid to hyper-arid catchments (Table 1).
2. Sensitivity ranking (Table 1): A one-at-a-time (OAT) sensitivity analysis was performed. Each parameter was varied by ±10% while keeping others constant, and the resulting change in the Nash–Sutcliffe efficiency (NSE) was recorded. Parameters were then ranked from 1 (most sensitive) to 4 (least sensitive) based on the magnitude of NSE change.
3. Iterative calibration procedure: The calibration was conducted in three sequential phases:

- Phase I (Surface runoff parameters): CN2, SURLAG, LAT_TTIME, CANMX, EPCO, and TLAPS were adjusted first, as they directly control surface and lateral flow.
- Phase II (Groundwater and soil parameters): GWQMN, ALPHA_BF, SOL_AWC, SOL_K, and SOL_BD were calibrated next to refine baseflow and soil moisture dynamics.
- Phase III (Sediment and channel parameters): USLE_K, CH_N2, CH_COV1, CH_EQN, PRF_BSN, OV_N, and C_FACTOR were adjusted to improve sediment load estimates.

4. Number of iterations: A total of 320 model runs were performed during calibration (200 runs for flow, 120 runs for sediment) and 160 runs during validation.
5. Convergence criterion: Manual iteration continued until the absolute change in NSE between successive runs was less than 0.005 for three consecutive runs, indicating that further parameter adjustments yielded negligible improvement.
6. Handling parameter interactions: Parameter interactions were managed by adjusting interdependent parameters (e.g., CN2 with SURLAG, or SOL_K with ALPHA_BF) in paired combinations and monitoring the combined effect on NSE. This was repeated until the optimal combination was identified.

7. Final parameter selection: The optimal parameter set (Table 1, last column) was selected when both R^2 and NSE reached their maximum stable values without further improvement after five additional runs.

This structured manual approach, though more time-consuming than automated algorithms, provides full transparency and allows for a deeper understanding of watershed-specific parameter behavior.

2.9. Simulation Scenarios

In this study, the SWAT model was executed under two distinct scenarios:

1. Control Scenario (Natural Conditions): The model was run for the control sub-catchment with no modifications to the natural hydrological system. This scenario represents the baseline or reference condition, where no watershed management interventions (check dams) have been implemented. The purpose of this scenario was to establish the natural flow and sediment regime against which the treatment scenario could be compared.

2. Treatment Scenario (With Check Dams): The model was run for the treatment sub-catchment where several check dams have been constructed. The presence of check dams alters the flow regime by reducing peak discharge, increasing infiltration, and trapping sediment. This scenario represents the managed condition and was used to evaluate the hydrological and sedimentological impacts of check dams in the Dehgin watershed.

Both scenarios were simulated on a monthly time step for the period 2005–2020. The model was calibrated for the period 2007–2015 and validated for the period 2016–2020. No future climate or land-use change scenarios were considered in this study; the focus was solely on evaluating the model's capability to simulate the paired catchments under current conditions.

3 Results and Discussion

3.1. SWAT Simulation

In this study, a DEM with a resolution of 12.5 m (ALOS PALSAR) was selected for simulating the Dehgin paired catchment.Subsequently, ArcSWAT software was used to delineate the sub-basins and the watershed boundary. As shown in Figure (2), a total of 10 sub-basins were delineated. The land use map was extracted using Google Earth Engine as well as a map prepared by the Natural Resources Administration. Additionally, a detailed soil map based on previous studies and reports conducted in the region was employed. After integrating the land use map, soil map, and slope classes, a total of 14 Hydrologic Response Units (HRUs) were obtained.

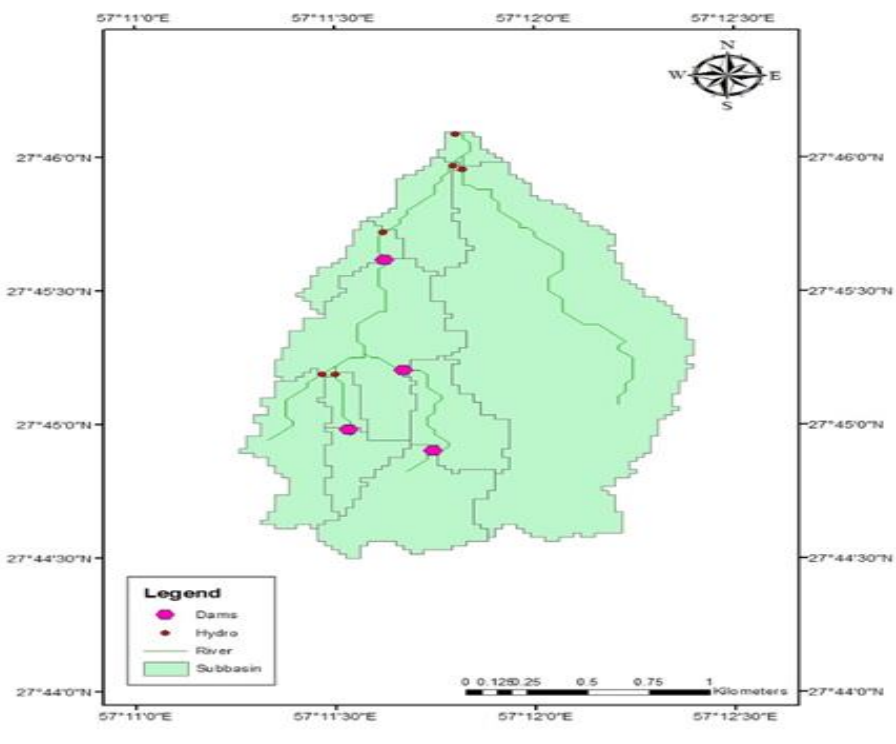


Figure 2. Extracted map from the SWAT model

To complete the modeling process, the model was run on a monthly basis for the statistical period from 2005 to 2020 and was evaluated against actual hydrometric and sediment data from the region. It should be noted that SWAT-CUP software was not used in this study;

instead, each parameter was manually calibrated by considering the R^2 and NSE evaluation indices. The parameters influencing flow and sediment routing that were investigated and given particular importance in this research are presented in Table 1. The objective of this approach was to select effective and optimal parameters for simulation and to determine their impact on characterizing the behavioral performance of the paired catchment. As indicated in Table 1, by running the model, the average values of parameters for each sub-basin are calculated. Calculating these parameters is important for two reasons. First, it prevents repetitive calculations during certain stages of model calibration, thereby significantly reducing the time required to rerun the model for optimizing its general parameters. Second, these intermediate outputs are highly valuable in hydrology, as they serve as inputs to many distributed and semi-distributed hydrological models. By running the SWAT model, these parameters can be computed for any watershed and utilized in various projects. Based on the obtained results, the study area exhibited excellent calibration results for streamflow simulation over the period 2007–2015, evaluated using R^2 and NSE. According to Table 2, the evaluation indices for the control catchment were 0.80 and 0.86, while for the treatment catchment they were 0.65 and 0.78, respectively. As shown in Figures 3 and 4, the model captures the general pattern of observed discharge, including low-flow and peak-flow events, with reasonable accuracy. However, some discrepancies are observed, particularly during extreme rainfall events, which are likely attributable to uncertainties in the input climatic data (e.g., spatial interpolation of precipitation from sparse rain gauges) and the model's simplified representation of check-dam impacts on flow routing. Regarding sediment evaluation for both the control and treatment catchments, considering the R^2 and NSE indices, the control catchment yielded values of 0.69 and 0.73, while the treatment catchment yielded 0.63 and 0.71, indicating proper modeling performance and optimal selection of parameter ranges for each sub-basin. The simulated versus observed sediment evaluation graphs for both catchments are presented in Figures 5 and 6. After calibration by fixing the parameter ranges, model validation was performed for the period 2016–2020. The model showed appropriate performance for discharge in the control catchment, with R^2 and NSE values of 0.88 and 0.92, indicating high modeling quality. For the treatment catchment, values of NSE = 0.58 and $R^2 = 0.80$ were obtained, indicating satisfactory model performance during validation despite the manipulations made within the catchment. For sediment validation over the 2016–2020 period, the control catchment yielded R^2 and NSE values of 0.59 and 0.65, indicating good performance, while the treatment catchment yielded NSE = 0.65 and $R^2 = 0.85$, indicating good performance for sediment load simulation during validation.

Table 1. Parameters Influencing Watershed Flow and Sediment

Parameter Name	Abbreviation	Sensitivity Rank	Variation Range		Optimal Value
Curve number	CN2	1	-0.6	0.6	0.3
Lateral flow travel time	LAT_TTIME	2	0	180	45
Surface runoff lag coefficient	SURLAG	3	0	100	35
Maximum canopy storage	CANMX	4	0	1	0.5
Threshold water depth in shallow aquifer for return flow	GWQMN	4	0	1	0.2
Soil evaporation compensation factor	EPCO	3	0	1	0.35
Precipitation lapse rate	TLAPS	3	0	10	4.5

Baseflow recession constant	ALPHA_BF	2	0	1	0.35
Available soil water capacity	SOL_AWC	2	-0.8	0.8	0.25
Saturated hydraulic conductivity	SOL_K	1	0	1	0.36
Moist soil albedo	SOL_BD	2	0	1	0.45
Soil erodibility factor	USLE_K	3	0	1	0.55
Manning's n for main channel	CH_N2	2	0.01	0.07	0.025
Channel erodibility factor	CH_COV1	1	0	1	0.36
Sediment transport equation method	CH_EQN	1	1	4	3
Peak rate adjustment factor for sediment routing in channel	PRF_BSN	3	0	1	0.5
Manning's n for overland flow	OV_N	2	0.01	1	0.35
Scaling parameter for cover and management factor in erosion model	C_FACTOR	4	0	1	0.45

The TLAPS range was adjusted from the default (0–10 °C/km) to 2–8 °C/km based on regional lapse rate studies in southern Iran (McVicar et al., 2007), which better represents the hyper-arid conditions of the study area. The optimal SURLAG value of 35 is higher than typical values reported for arid catchments (usually 1–5). This deviation is attributed to the low-permeability bedrock and the high-intensity, short-duration rainfall events characteristic of this hyper-arid region, which generate rapid surface runoff with minimal lag. A higher SURLAG value was necessary to smooth the sharp peaks observed in the treatment catchment, where check dams alter the flow regime.

Table 1 presents the key parameters influencing streamflow and sediment simulation in the SWAT model, along with their sensitivity ranking, variation ranges, and optimal values obtained through manual calibration. The curve number (CN2) was identified as the most sensitive parameter (rank 1), which is consistent with previous studies demonstrating its dominant role in surface runoff estimation (Neitsch et al., 2011). Other highly sensitive parameters included saturated hydraulic conductivity (SOL_K), baseflow recession constant (ALPHA_BF), and available soil water capacity (SOL_AWC), all of which are widely recognized as critical for hydrological modeling (Arnold et al., 2012). The optimal parameter values were determined by iteratively adjusting each parameter within its defined range while monitoring the R^2 and Nash–Satcliffe efficiency (NSE) indices. This manual calibration approach, although time-consuming, allows for a thorough understanding of parameter sensitivity and watershed behavior (Abbaspour et al., 2015).

Table 2. Evaluation of Flow and Sediment Simulation Results in the Dehgin Paired Catchment

Watershed	Flow Simulation Calibration		Validation		Sediment Simulation Calibration		Validation	
	R^2	NSE	R^2	NSE	R^2	NSE	R^2	NSE
Control	0.86	0.8	0.92	0.88	0.73	0.69	0.65	0.59
Treatment	0.78	0.65	0.8	0.58	0.83	0.71	0.85	0.65

Rating criteria: NSE ≥ 0.75 = Very Good; 0.65–0.75 = Good; 0.50–0.65 = Satisfactory; < 0.50 = Unsatisfactory (Moriasi et al., 2007).

Table 2 summarizes the performance evaluation of The SWAT model was calibrated manually following the step-by-step protocol described in Section 2.8. The calibration period covered 2007–2015, and the validation period covered 2016–2020. Calibration was performed separately for streamflow and sediment yield using monthly observed data. The curve number (CN2), saturated hydraulic conductivity (SOL_K), and baseflow recession constant (ALPHA_BF) were identified as the most sensitive parameters (Table 1).

The objective function for calibration was to maximize the Nash–Sutcliffe Efficiency (NSE) and coefficient of determination (R^2) while minimizing the percent bias (PBIAS). A total of 320 model runs were performed during calibration (200 for flow, 120 for sediment), and the convergence criterion (NSE change < 0.005 for three consecutive runs) was achieved after approximately 180 runs for flow and 100 runs for sediment.

3.2.Simulation Accuracy

The model demonstrated high accuracy for streamflow simulation in the control catchment, achieving "Very Good" performance during both calibration (R^2 = 0.86, NSE = 0.80) and validation (R^2 = 0.92, NSE = 0.88) periods. The treatment catchment showed "Good" to "Satisfactory" performance (calibration: R^2 = 0.78, NSE = 0.65 – Good; validation: R^2 = 0.80, NSE = 0.58 – Satisfactory), with the reduced efficiency attributed to hydrological disturbances caused by check dams.

For sediment simulation, both catchments demonstrated "Satisfactory" to "Good" performance, with NSE values ranging from 0.59 to 0.71. The treatment catchment performed better in sediment simulation (calibration: R^2 = 0.83, NSE = 0.71 – Good; validation: R^2 = 0.85, NSE = 0.65 – Good) compared to the control catchment, which is attributed to sediment trapping behind check dams.

The overall results indicate that the SWAT model is capable of simulating monthly runoff discharge and sediment yield in the Dehgin paired catchment with acceptable accuracy (NSE > 0.50 for all simulations). The model performs better in the control catchment than in the treatment catchment due to the simplified representation of check dam impacts in the SWAT model, which is a known limitation of the model. Nevertheless, the accuracy achieved in this study is comparable to similar SWAT applications in arid and semi-arid regions (Gassman et al., 2007; Mengistu et al., 2019).
In addition to the scatter plots (Figures 3–6), time-series plots of observed versus simulated daily discharge and sediment load are presented in Figures 7–10 present the time-series plots of observed versus simulated daily discharge and sediment load for both control and treatment catchments during calibration (2007–2015) and validation (2016–2020) periods. These plots allow for visual assessment of model performance in capturing peak events and seasonal patterns.

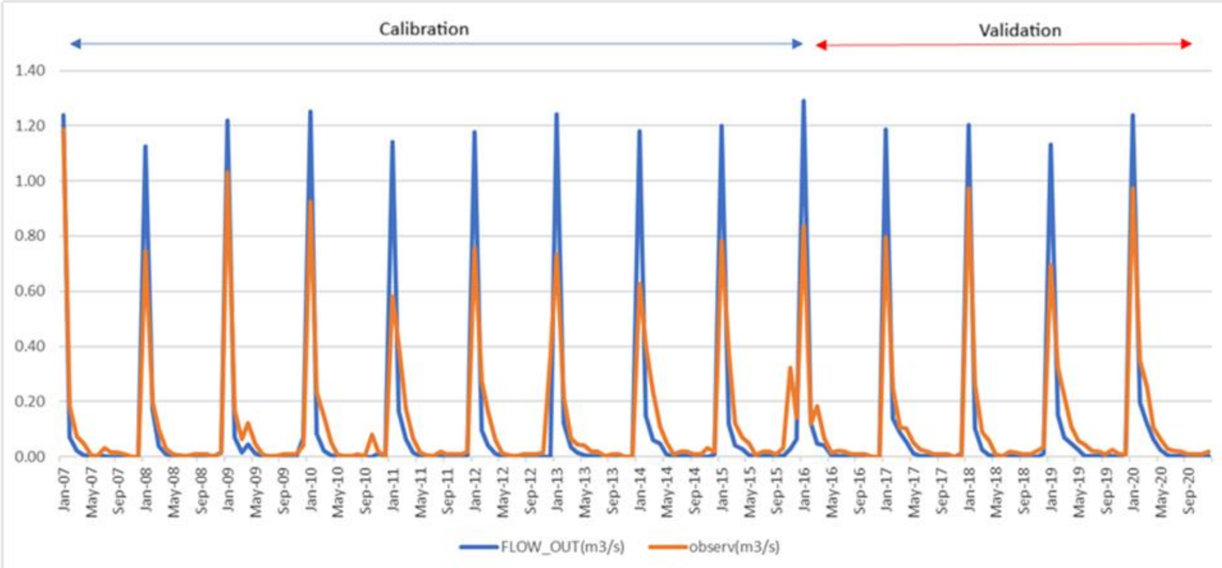


Figure 3. Evaluation of the flow hydrograph for the control catchment

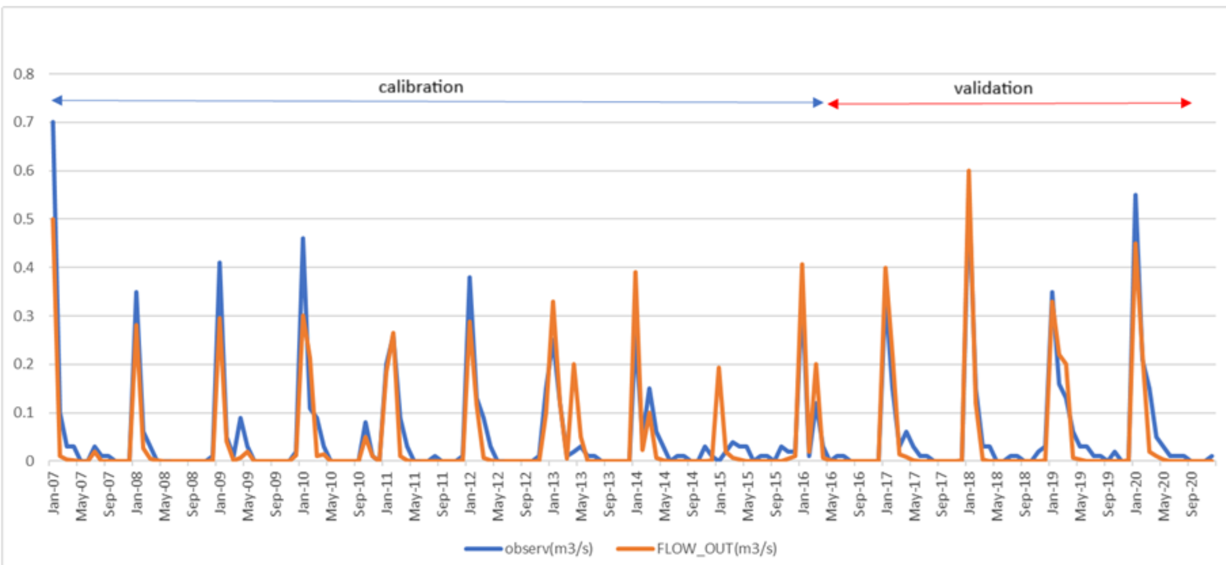


Figure 4. Evaluation of the flow hydrograph for the treatment catchment

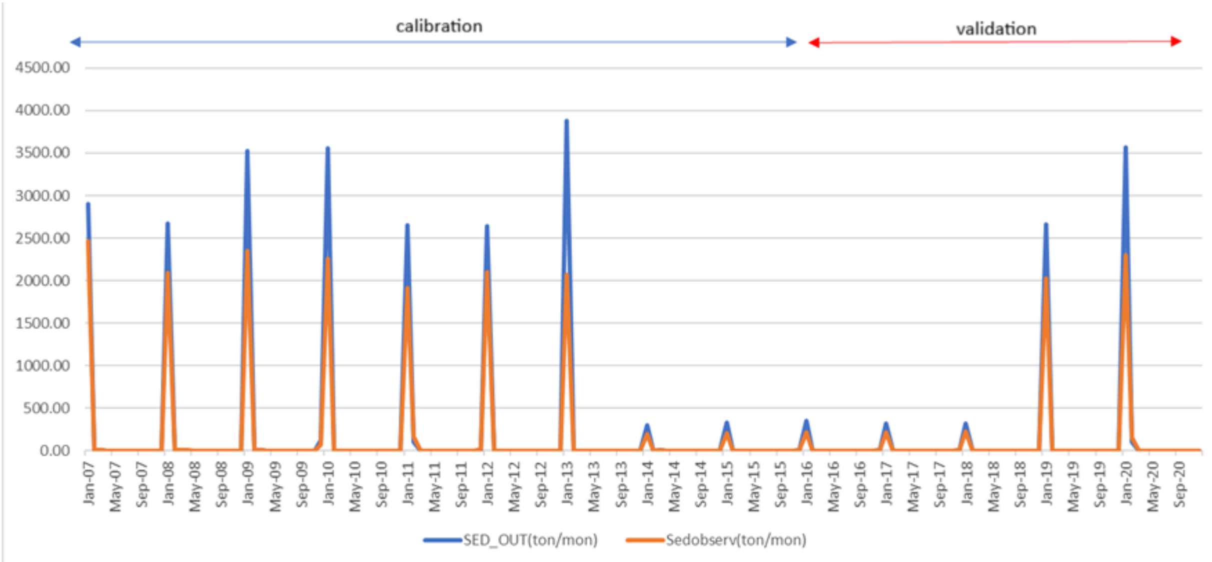
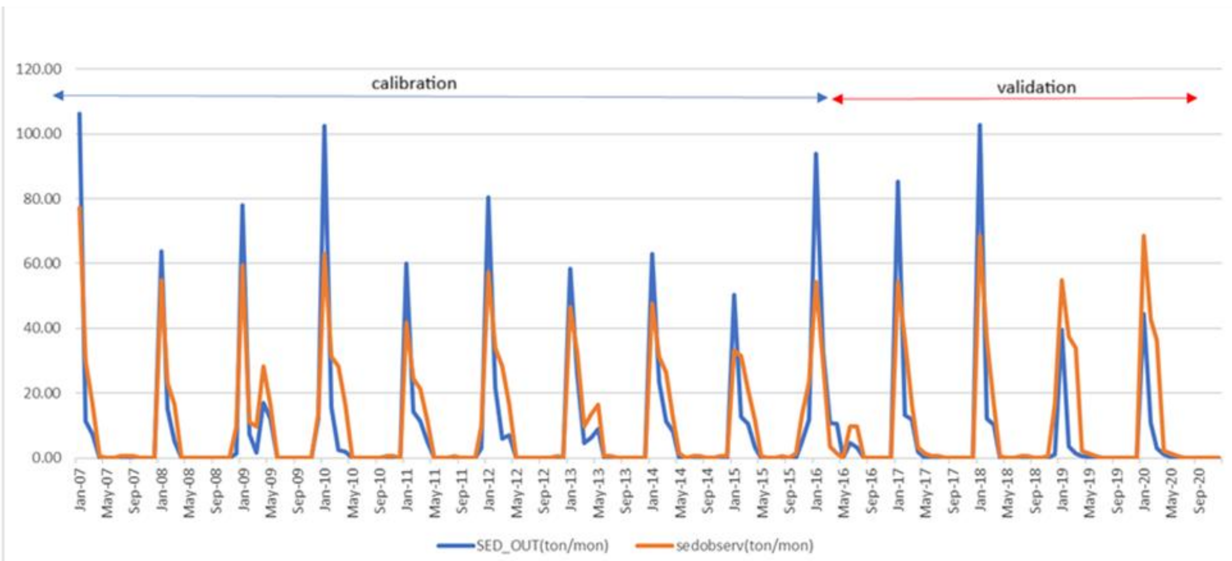


Figure 5. Evaluation of the sediment hydrograph for the control catchment



Figurr 6. Evaluation of the sediment hydrograph for the treatment catchment

4. Conclusion

By running the SWAT model in the Dehgin watershed and comparing the observed hydrographs with the simulated flow and sediment hydrographs through both visual and statistical analyses, it was determined that there is strong similarity between the simulated and observed hydrographs during the study period. Furthermore, key hydrograph characteristics such as instantaneous peak discharge, runoff volume, and time to peak discharge exhibited good agreement between the two hydrographs.

Evaluation of the statistical indices and graphs obtained during the calibration and validation stages for monthly runoff and sediment simulation indicates that the model performed more successfully during the validation stage. Overall, the results demonstrate the acceptable capability and accuracy of the SWAT model in simulating monthly runoff discharge and sediment yield in the Dehgin watershed—a paired catchment where the treatment sub-basin has experienced environmental manipulations (construction of check dams) while the control sub-basin remains undisturbed. The model successfully simulated both catchments simultaneously.

Based on the sensitivity analysis results, 19 parameters affecting runoff and sediment were identified in the SWAT model. The curve number (CN2), lateral flow travel time (LAT_TTIME), threshold water depth in the shallow aquifer for return flow (GWQMN), soil evaporation compensation factor (EPCO), and maximum canopy storage (CANMX) were recognized as the most critical parameters for determining runoff discharge from the watershed. For sediment simulation, the sediment transport equation method (CH_EQN), soil erodibility factor (USLE_K), saturated hydraulic conductivity (SOL_K), and channel erodibility factor (CH_COV1) were identified as the most influential parameters.

Therefore, it can be concluded that, based on the obtained results, the semi-distributed SWAT model is suitable for evaluating paired catchments.

References

Aghajan Liafo, F., & Nazarnejad, H. (2024). Mudelsazi-ye farseh va resob va shabisazi-ye asar-e eqdamat-e hefazati dar howzeh-ye Chehel-Chay-e ostan-e Golestan ba model-e SWAT+ [Modeling of erosion and sediment and simulation of the effects of conservation measures in the Chehel-Chai watershed, Golestan Province, using the SWAT+ model] (Master's thesis). Gorgan University of Agricultural Sciences and Natural Resources.

Aghakhani, M., Nasrabadi, T., & Vafaieinejad, A. R. (2019). Shabisazi-ye hydrolozhiki-ye howzeh-ye abkhiz-e Taleghan ba estefadeh az model-e SWAT [Hydrological simulation of the Taleghan watershed using the SWAT model]. *Journal of Environmental Science and Technology*, 9(21), 149–159.

Ahmadi, R., Kavyan, A., & Gholami, L. (2023). Arzyabi-ye asar-e eqdamat-e hefazat-e ab va khak dar bakhshi az howzeh-ye abkhiz-e Tajan, Sari [Evaluation of the effects of water and soil conservation measures in a part of the Tajan watershed, Sari] (Doctoral dissertation). Sari University of Agricultural Sciences and Natural Resources.

Alberto, M., & Carmelo, C. (2020). Suitability of the SWAT model for simulating water discharge and sediment load in a karst watershed of the semiarid Mediterranean basin. *Water Resources Management*, 34(2), 123–140.

Alizadeh, A., Izady, A., Davari, K., Ziaei, A. N., Akhavan, S., & Hamidi, Z. (2013). Estimation of actual evapotranspiration at regional–annual scale using SWAT. *Journal of Water and Soil*, 7(2), 243–258.

Amiri, M., Ghanbarpour, M. R., Mirkhalgh, Z. T. A., & Saravi, M. (2008). Kalibrasyon va arzyabi-ye model-e hydrolozhiki-ye SWAT baraye shabisazi-ye ravanab va bilan-e abi-ye howzeh-ye abkhiz-e maref-e zuji-ye Kasilian [Calibration and evaluation of the SWAT hydrological model for runoff and water balance simulation in the Kasilian paired representative catchment]. *Journal of the Faculty of Natural Resources*, 61(4), 797–808.

Ansarifard, S., Ghorbanifard, M., Boustani, F., & Abdolazimi, H. (2024). Hydrological simulation and evaluation of drought conditions in the ungauged watershed Parishan lake Iran, using the SWAT model. *Journal of Water and Climate Change*, 15(9), 4666–4698.

Drini, B., Ghaderi, K., & Ahmadi, M. M. (2023). Shabisazi-ye hydrolozhiki-ye howzeh-ye abkhiz-e Riz Gelleh va Shahr-e Babak ba estefadeh az model-e SWAT [Hydrological simulation of the Riz Gelleh and Shahr-e Babak watershed using the SWAT model] (Master's thesis). Shahid Bahonar University of Kerman.

Gholami, Sh. (2000). Shabisazi-ye resob-e ruzaneh ba estefadeh az model-e toziyi-e SWAT dar howzeh-haye kuhestani (howzeh-ye abkhiz-e maref-e zuji-ye

Emameh) [Daily sediment simulation using the SWAT distributed model in mountainous catchments (Emameh paired representative catchment)]. In *Proceedings of the Second National Conference on Erosion and Sediment* (pp. 185–204).

Goudarzi, M., Zahabiyoun, B., & Masah Bavani, A. (2016). Shabisazi-ye baran-ravanab-e howzeh-ye Ghareh Su ba estefadeh az model-e SWAT [Rainfall-runoff simulation of the Ghareh Su watershed using the SWAT model]. *Journal of Environmental Science and Technology*, 18(2), 11–20.

Green, C. H., Gassman, P. W., Williams, J. R., Haney, R., & Harmel, R. D. (2007). Soil and water assessment tool hydrologic and water quality evaluation of the Little River watershed. *Transactions of the ASABE*, 50(5), 1577–1588.

Hajimohammadi, M., Nazari Samani, A. A., Zare Garizi, A., Keshtkar, H., Arab Khedri, M., & Saadaldin, A. (2022). Tafif-e vahd-ha-ye vakenesh-e hydrolozhiki-ye peyvaste-ye makani baraye model-sazi-ye hydrolozhiki dar howzeh-ye abkhiz-e kuhestani ba SWAT (motale'eh-ye moredi: howzeh-ye abkhiz-e Taleghan) [Definition of spatially continuous hydrologic response units for hydrological modeling in a mountainous watershed using SWAT (Case study: Taleghan Watershed)]. *Journal of Rangeland and Watershed Management*, 75(2), 213–226.

Hershfield, D. M. (1961). *Rainfall frequency atlas of the U.S for durations from 30 min to 24 hours and return periods from 1 to 100 years* (U.S. Dep. Commerce Tech. paper No. 40).

Honglei, Z., Ying, L., Zhaoli, L., Xiaoliang, S., Bolin, F., & Zefeng, X. (2015). Using SWAT to simulate streamflow in Huifa River basin with ground and Fengyun precipitation data. *Journal of Hydroinformatics*, 17(5), 834–844.

Kavianpour, M. R., & Sadat Mirsane, Z. (2011). Shabisazi-ye hydrolozhiki-ye howzeh-ye abriz-e Kashkan bevasile-ye model-e SWAT2005 [Hydrological simulation of the Kashkan catchment using the SWAT2005 model]. In *Proceedings of the Fourth Iranian Conference on Water Resources Management*. Amirkabir University of Technology.

Kazemzadeh, M. (2018). *Shenasnameh-ye prozeh-ye howzeh-ye maref va zuji-ye Zidasht-e Taleghan-e ostan-e Alborz* [Project documentation of the Zidasht representative and paired catchment, Taleghan, Alborz Province]. Office of Watershed Management and Soil Conservation, Forests, Rangelands and Watershed Management Organization.

Liu, Y., Xu, Y., Zhao, Y., & Long, Y. (2022). Using SWAT model to assess the impacts of land use and climate changes on flood in the Upper Weihe River, China. *Water*, 14(13), 2098.

Lucas, M., Marcelo, R., Marx, L., Diego, F. A., & Nilton, C. (2016). Hydrological modeling of tributaries of Cantareira System southeast Brazil with the SWAT model. *Journal of the Brazilian Association of Agricultural Engineering*, 1037–1049.

Maleki, S., Khermandar, K., Hosseinalizadeh, M., Goli Jirandeh, A., Kornejadi, A., & Pourghasemi, H. R. (2022). New methods in soil science studies in paired watersheds with an approach to updating service description in paired watersheds of Dehgin, Hormozgan Province. *Pazhouhesh-haye Abkhizdari*, 35(3), 60–80.

Memarian, H., Balasundram, S. K., Abbaspour, K. C., Talib, J. B., Sung, C. T. B., & Sood, A. C. (2014). SWAT-based hydrological modelling of tropical land use scenarios. *Hydrological Sciences Journal*.

Mengistu, A. G., Remsburg, L. D. V. L., & Woyessa, Y. E. (2019). Techniques for calibration and validation of SWAT model in data scarce arid and semi-arid catchments in South Africa. *Journal of Hydrology: Regional Studies*, 1–18.

Moslehi, M., & Hassanzadeh Khankahdani, H. (2020). Investigating the effects of different methods of precipitation storage on soil moisture and growth characteristics of Acacia oerfota (Forssk) Schweinf seedlings: A case study of paired watershed of Dehgin, Hormozgan Province. *Desert Ecosystem Engineering Journal*, 9(26), 61–72.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I – A discussion of principles. *Journal of Hydrology*, 10, 282–290.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). *Soil and water assessment tool theoretical documentation version 2009*. Texas Water Resources Institute.

Nik-Khah Amiri, S., Khoshrowsh, M., & Norouz Valashedi, R. (2018). Shabisazi-ye seri-ye zamani-ye jaryan dar mahd-e khoruji-ye sad-e Shahid Rajaei ba estefadeh az model-e SWAT [Simulation of the time series of flow at the outlet of Shahid Rajaei Dam using the SWAT model]. *Iranian Journal of Irrigation and Water Engineering*, 1(37), 67–81.

Norafkan, A. H., Akhtari, R., & Delavar, M. (2021). Arzyabi-ye tasirat-e eqdamat-e abkhizdari bar moalefe-haye bilan-e abi va resob (motale'eh-ye moredi: howzeh-ye abriz-e Vardij–Varish) [Evaluation of the impacts of watershed management measures on water balance and sediment components (Case study: Vardij–Varish catchment)]. *Iranian Water Resources Research*, 17(1), 277–289.

Parvizi, Y., & Arabkhedri, M. (2022). Understanding the convergence of extreme events of precipitation, soil erosion and flow in the representative and paired watersheds of Dehgin, Hormozgan. *Water Harvesting Research*, 5(1), 80–92.

Rahman, K., Maringantic, H., Beniston, M., Widmer, F., Abbaspour, K., & Lehmann, A. (2013). Streamflow modeling in a highly managed mountainous glacier watershed using SWAT: The Upper Rhone River watershed case in Switzerland. *Water Resources Management*, 27(2), 323–339.

Rivas-Tabares, D., Tarquis, A. N., Willaarts, B., & Miguel, A. (2019). An accurate evaluation of water availability in sub-arid Mediterranean watersheds through SWAT: Cega-Eresma-Adaja. *Journal of Agricultural Water Management*, 212, 211–225.

Saadati, H., Gholami, Sh. A., Sharifi, F., & Ayoubzadeh, A. (2006). Barresi-ye asar-e taghir-e karbri-ye arzahi bar ravanab-e sehi-ye howzeh-ye maref-e zuji-ye Kasilian ba estefadeh az model-e SWAT [Investigation of land use change effects on surface runoff in the Kasilian paired representative catchment using the SWAT model]. *Iranian Journal of Natural Resources*, 59(2), 301–313.

Sanjay Shekar, N. C., & Vinay, D. C. (2021). Performance of HEC-HMS and SWAT to simulate streamflow in the sub-humid tropical Hemavathi catchment. *Journal of Water and Climate Change*, 1–12.

Williams, J. R., & Singh, V. (1995). Computer models of watershed hydrology. In *Water Resources Publications* (pp. 909–1000). Highlands Ranch.

Yan, R., Li, L., & Gao, J. (2025). A novel framework for tracking hydrological processes and identifying key factors in mountain-lowland mixed catchments: Implications of forty years of modeling for water management. *Journal of Hydrology*, 279, 123424.

Zahedi, E., Talebi, A., Davari, K., & Mousavi, V. (2022). Shabisazi-ye hydrolozhik-e howzeh-ye abkhiz-e Samghan ba estefadeh az model-e SWAT [Hydrological simulation of the Samghan watershed using the SWAT model]. *Geography and Human Relations*, 5(3), 221–237.

Zohayri, Z., Ghazavi, R., & Omidvar, E. (2025). Evaluating the hydrologic control of check dam systems under combined climate and land-use change scenarios in a semi-arid watershed, Iran. *ECOPERSIA*, 13(4), 391–405.