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Simulation of sediment accumulation for the river watershed using SWAT software: A case study on Ahar Chai river watershed in northwest of Iran

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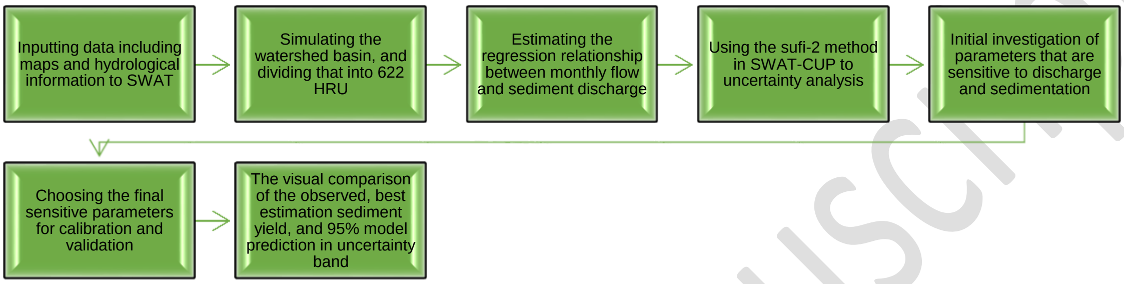
GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the results of a study that simulates the sediment routing of the Ahar Chai river using the hydrologic model which calculates the accuracy of using the soil and water assessment tool (SWAT) to simulate the runoff and sediment in watershed areas that could help to predict the amount of sediment in the future. Therefore, in this paper, sediment production in the upper Ahar Chai watershed, located in East Azarbaijan province - Ahar city, was simulated by using the hydrological model of SWAT, which is an addition to the Arc-GIS environment. The model's effectiveness in this area's hydrological simulation was assessed. sequential uncertainty fitting-2 (sufi-2), a SWAT-CUP sub-module computer program was applied to optimize the parameters of SWAT using monthly observed runoff and sediment data at the Ahar Chai watershed for calibration, validation, and uncertainty analysis. In the climatological studies, data from the Ahar synoptic station were used from 1994 to 2015. The Ahar Chai basin model was used from 1994 to 2015 for precipitation data. The monthly average discharge and sediment data were also used from the Orang hydrometric and sedimentation station in the period 2000-2015. The observed statistical data of flow and sediment measured for 22 years were selected for model simulation. The determination coefficient (R^2) and the Nash-Sutcliffe coefficient (NS) in the calibration stage for sedimentation were 0.81 and 0.66 respectively, and also in the validation stage, were 0.74 and 0.71. The results highlight the model's potential for simulating sediment yield and streamflow under varying climatic and land use conditions, with performance metrics comparable to those found in similar global studies. However, this study also provides unique insights into the regional-specific challenges of applying SWAT in regions with high variability in precipitation, land use, and topography. Notably, the influence of vegetation covers on sediment yield, as well as the importance of high-quality, region-specific data for model calibration, are key findings. This research contributes to the broader body of knowledge by offering an in-depth analysis of SWAT's performance in the Ahar Chai basin, while also addressing the gaps in current modeling efforts related to sediment transport in mountainous, semi-arid environments. The findings pave the way for future advancements in hydrological modeling and watershed management in similar regions, particularly through the integration of more detailed data and enhanced uncertainty analysis methods.

1. Introduction

Rivers serve as a significant source of water to meet various types of human needs (Anyanwu *et al.*, 2022; Rasi Nezami and Aghlmand, 2023). "Unregulated socioeconomic activities (such as siting of industries and disposal of effluents into rivers) and inappropriate societal behaviors (like disposal of wastes in drainages and rivers) have seriously resulted in pollution of rivers" (Odero *et al.*, 2023; Anyanwu *et*

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al., 2024). Runoff and the ensuing impact on sediment movement are among the present problems in watershed basins. The ensuing economic effects are the most significant side effects of sedimentation in rivers. In order to maximize the use of the river, minimize its negative effects, and provide the information needed for management measures to reduce the amount of incoming sediment and prevent its erosion for nature protection, it is imperative to simulate the rate of sediment production and transport and identify the dominant sub-basin in its production. The first stage in combating erosion, a problem that is also regarded as an environmental pollutant, is determining its contributing components. The primary causes are the growing population and the improper and excessive usage of land. The following stage should provide detailed information on various executive and managing techniques. Reliable estimates of the elements of the water balance, such as runoff, sediment, evapotranspiration, infiltration, and groundwater flow, are necessary for operational hydrology and water resource management. Planning water resources (Gunathilake *et al.*, 2020a; Flores *et al.*, 2021), predicting floods (Gunathilake *et al.*, 2020b; Hanif *et al.*, 2020), comprehending the hydrology resulting from changes in climate and land use (Bhatta *et al.*, 2019; Chen *et al.*, 2019), monitoring water quality (Zhou *et al.*, 2022), developing strategies for managing aquifer recharge (Mvandaba *et al.*, 2018), designing hydraulic infrastructure (Aureli *et al.*, 2021), designing ecological restorations (Peng *et al*., 2015) and so on are all done with the help of hydrologic models. The development of computer technology and programming has helped academics, industry, and researchers create various software to model watershed processes. The SWAT model (Arnold *et al*., 1998) , the hydrologiska byråns vattenbalansavdelning (HBV light) model (Bergström, 1992), and the hydrologic simulation program fortran (HSPF) model(Bicknell *et al*., 1997) are some of the widely used hydrologic models used in different regions of the world today (Đukić and Erić, 2021). Out of all the hydrological models used in this study, the SWAT model was selected to simulate the watershed under investigation. Since the SWAT model may be used to simulate enormous watersheds without requiring a lot of time or money, it is a continuous and computationally efficient model. Another benefit of this architecture is that it is simple to use and access for controlling input data (Abbaspour *et al*., 2007). The Ahar Chai watershed in East Azarbaijan province rises to a height of 2952 meters on Kasabeh mountain. It flows through the cities of Ahar and Varzeghan in a west-east direction before joining the Qara-su river in the eastern section of the basin at the basin's outlet, where it eventually joins the Aras river. The Sattar Khan dam, which was constructed on the Ahar Chai river 15 km from the city of Ahar and 120 km northeast of Tabriz, is the most significant hydraulic structure ever built in this basin. There aren't enough hydrometric stations in this basin because of its remote location and steep terrain. It is situated in a mountainous and steep area. Thus, it appears that to study and forecast the hydrological changes of the river in the future, hydrological models must be used to estimate the amount of river runoff and sediment. Recent studies have significantly advanced our understanding of sediment dynamics in reservoir dams and the strategies for effective management (Aryaei and Lashkar-Ara, 2023) emphasized the critical role of low-level outlets in managing sediment accumulation resulting from turbidity currents in the Dez dam. Furthermore, (Afrashte and Lashkar-Ara, 2025) highlighted sedimentation in settling basins as a significant challenge in water resource management, demonstrating that an increased aspect ratio of these basins correlates positively with their sediment trapping efficiency. Additionally, (Lashkar-Ara and Kiani, 2025) assessed various equations for estimating suspended sediment discharge in the Balaroud river, identifying the Rouse equation as the most accurate model for this river.

2. Material and methods

2.1. Description of the study area

Ahar Chai watershed is located northeast of the providence of East Azerbaijan shown in Fig.1. It covers an area of 2426 km^2, which is one of the approximately large watersheds in this zone. This watershed reaches the Arasbaran forest from the north, the Ghara Su river from the east, the Kasabe mountains area from the west, and the Aji Chai river from the south. The main river in this watershed is the Ahar Chai river which stems from the heights of Kasbeh mountain and flows from west to east.

2.2. Climate

A watershed's climate provides moisture and energy resources that control the water balance equation and determine the relative importance of different components of the hydrologic cycle. Climate variables required by SWAT model include daily precipitation, minimum and maximum air temperature, solar radiation, wind speed and relative humidity.

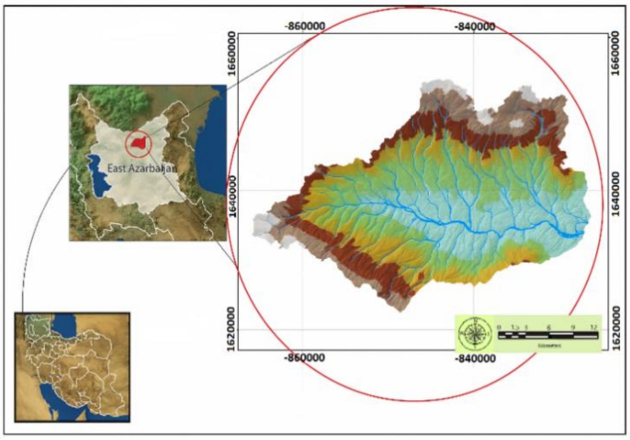


Fig. 1. Geographical location of the Ahar Chai watershed.

2.3. The temperature regime of Ahar chai basin

The temperature regime in the researched area based on the average temperature in the hydrometric station for 1994-2015 was estimated. During these 22 years in this watershed, the lowest temperature in January was -4.89 degrees Celsius while the maximum was 28.12 degrees Celsius in August. Fig. 2 shows the highest and lowest monthly temperatures during a 22-year period at the Ahar observation station.

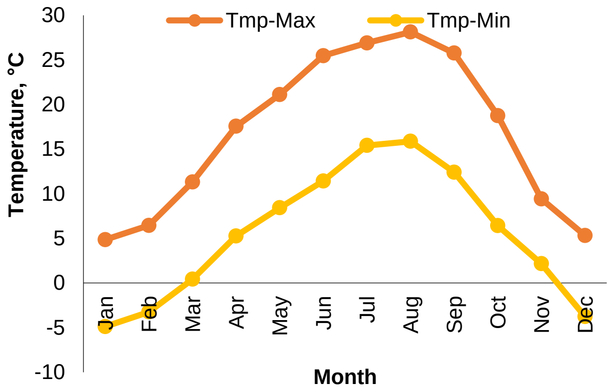


Fig. 2. Monthly temperature variations at the orang hydrometric station for the period 1994-2015.

2.4. Discharge regime of the upper Ahar Chai basin

Ahar Chai's flow rate varies throughout the year; it reaches its maximum in the spring when precipitation increases and snowmelts, and its lowest point in the summer when precipitation decreases and snow accumulation ends. Fig.3 depicts the monthly variations and changes in the Ahar Chai river's discharge over a 22-year span (1994-2015). The Ahar Chai river's maximum monthly flow is set in the spring, and its minimum flow occurs in August. As a result, Ahar Chai has a variable hydrological regime, a kind of rain and snow regime. At Orang station, the average yearly discharge of Ahar Chai is 1.76 m^3.

2.5. Data used

The digital elevation model (DEM), land use map, soil map, rainfall, minimum and maximum daily temperature, meteorological data, and river discharge at the hydrometric station are among the spatial variables, hydroclimatological, and numerical variables that the model requires. It is situated in the basin's upstream outlet, and the procedures are carried out by calibrating the sediment values at the sediment measurement station within the basin. The Ahar synoptic station data were used for the years 1994–2015 in the climatology studies. The upper Ahar Chai basin's Baransji stations—Verdin, Kasin, Ovilaq, Orang, and Ahar—were used to collect model precipitation data between 1989 and 2015. The Orang hydrometric and sedimentation station's average monthly discharge and sediment data for the years 2000–2015 were also use.

2.6. General introduction of research steps

The SWAT model is one of several models used today to simulate the hydrology of watersheds around the globe. It considers various data layers, including soil maps, land use, and DEM. This research model, which is meant for the Ahar Chai basin, can simulate runoff, sedimentation, erosion, and chemical substance transfer in complex basins. The model is calibrated using the sufi-2 algorithm and SWAT-CUP software. In this manner, the DEM and soil and land use maps for the Ahar Chai basin were prepared and added to the SWAT model.

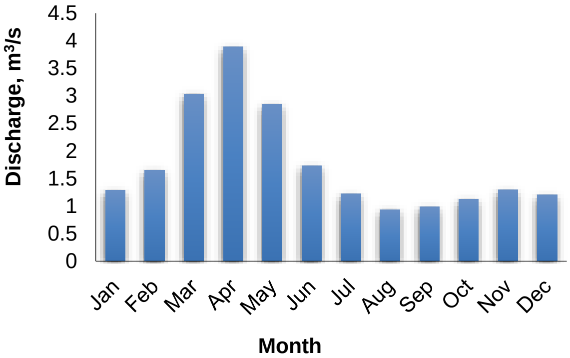


Fig. 3. Monthly discharge variation at the orang hydrometric station for the period 1994-2015.

2.7. SWAT model introduction

The SWAT model functions on a daily time step basis, developed by the USDA's agricultural research services (ARS). This tool is practical in evaluating hydrological processes and non-point source pollution across the mixed variety of spatial scales. This model segments a watershed area into multiple smaller ones, which are further divided into hydrologic response units(HRUs); These HRUs are constructed by combinations areas with similar characteristics including land use, soil, and slope (Akoko *et al*., 2021). While HRUs illustrate percentages of sub-basin areas, they are not spatially associated within model simulations (Pignotti *et al*., 2017). The fundamental equation governing SWAT model is the water balance equation which is given in equation (1) (Marahatta , Devkota and Aryal, 2021).

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

SW_t: the final amount of water in the soil in millimeters, SW_0: the initial amount of water in the soil in millimeters (up to a depth of 30 cm), t : time in days, R_{day} : the amount of precipitation on day i in millimeters, Q_{surf} : the amount of surface runoff on day i in millimeters, W_{seep} : the amount of water infiltrating the upper soil layer (unsaturated zone) on day i in millimeters, Q_{gw} : the flow of underground water exiting to the river on day i in millimeters and E_a : the amount of evaporation and sweating.

2.8. Estimation of erosion and sedimentation

Sediment in rivers typically refers to the detachment, transport, and deposition of soil particles caused by the erosive force of rain or surface water flow. The basin's surface features a great number of channels and small streams. Also, raindrops dislodge particles from the ground, which are then carried into rills, temporary channels, and eventually into the river's permanent flow, so particles may be transported by the main channel and settled at various locations. This process is significantly observed on surfaces lacking of vegetation. The modified universal soil loss equation (MUSLE) is the basis for forecasting the amount of soil erosion which is estimated by taking account of the precipitation and runoff on the SWAT model. This formula is a modified version of the universal soil loss equation (USLE). The USLE equation only takes into account erosion brought on by rainfall; it does not predict erosion brought on by snowmelt runoff. However, it is also feasible to compute the erosion brought on by snowmelt using the MUSLE equation. The suspended load sediments on a watershed's surface can be calculated using the SWAT model. The SWAT model can also be used to estimate the amount of suspended sediment output and the sediments that have settled in the dam reservoir. Based on the volume and concentration of the inflow, outflow, and remaining water in the dam reservoir, the sediment concentration in the reservoir is computed. Additionally, the balance between sediment concentration and average particle diameter is used to calculate the amount of deposited sediments (Neitch *et al*., 2005).

The universal soil loss equation which cannot be used to estimate the sedimentation rate of watersheds, is provided to estimate the amount of soil loss from a piece of land or along a slope. Research has presented the weak and nonlinear connection between the percentage of sediment generation in the USLE equation and erosive factors. Consequently, because of variability in calculated sediment production ratios and the nonlinear relationship between the rainfall factor and sediment production value, the runoff factor in the model was replaced. Additionally, the global equation will eliminate the need for a sediment delivery ratio, as the runoff factor will substitute for the rainfall factor. Since the amount of runoff at watershed areas depends on the previous soil moisture, the MUSLE model has enhanced the simulation of sediment volume at the watershed levels. In contrast, the USLE model does not consider the previous water moisture when generating runoff, leading to sediment production. The general form of the MUSLE model, in which the role of runoff is an indicator and can be used to estimate the annual sediment, is as follows:

$$Sed_k = 11.8 * \left(Q_{surf} * q_{peak} * area_{hru}\right)^{0.56} K_{usle} * C_{usle} * p_{usle} * LS_{surf} * CFRG \quad (2)$$

where, Sed_K is the amount of sediment (tons per day), Q_{surf} is the runoff (mm per hectare), q_{surf} is the maximum runoff (cubic meters per second), $area_{hru}$ is the area of each HRU (hectare), K_{usle} is the soil erodibility factor in the global soil erosion equation, C_{usle} is the management factor and coverage in the global equation of soil erosion, P_{usle} is the factor of protective methods in the global equation of soil erosion, LS_{surf} is the topography factor in the global equation of soil erosion, and CFRG is the factor of coarse particles in the global equation of soil erosion, which is obtained from the following equation:

$$CFRG = \exp(-0.053 * Rock) \quad (3)$$

That rock is the percentage of rocks and pebbles in the surface layer of the soil (Neitch *et al.*, 2005).

2.9. Sensitivity analysis and model performance evaluation

Numerous parameters are needed for complex hydrological models like SWAT in order to provide the spatial distribution of watershed characteristics. Sensitivity analysis aids in identifying the parameters that have a significant impact on the model's output because it is impossible to measure every parameter. How a model is calibrated and validated determines its usefulness and reliability. Choosing and adjusting the model's influencing parameters until the simulation outputs fit the pre-established performance criteria and correspond with the real observations is the process of validation. While no parameter correction is carried out and the comparison of model output and observed values is in different time series with environmental conditions that differ from the calibration period, validation is comparable to calibration in that it compares simulated and observed data. The SWAT-CUP software has incorporated the sufi-2 method (Chu and Shirmohammadi, 2004) to enhance the quality of uncertainty analysis and calibration in model results while also saving time. In order to determine the parameter uncertainty so that the majority of the observed data fall within the established uncertainty region, the sufi-2 program combines calibration and uncertainty. It also aims to produce the narrowest possible range of uncertainty. For every parameter in this software, a wide initial range of uncertainty is assumed. As a result, the observational data are first set at a level of 95 ppu, and this uncertainty is subsequently decreased until the next two requirements are met:

1-Most of the observed data should be within the 95% uncertainty band or most of the observed data should be at the 95 ppu level. ($\boldsymbol{P_{factor}} \rightarrow \mathbf{1}$)

2-The average distance between the upper and lower limits, in the range of 95 % uncertainty divided by the standard deviation of the measured data, should be as small as possible. ($R_{factor} \rightarrow 0$).

2.10. Evaluation criteria of model efficiency

Because the sufi-2 method is random, it is not feasible to use some statistical parameters, like the coefficient of determination or the Nash-Sutcliffe coefficient, which are used to compare two signals. Instead, the variables in this method are given a 95% uncertainty band, and the quality of the fit is assessed by calculating the P-factor (the percentage of the observed variables that fall within the 95% uncertainty band) and the R-factor (the average distance between the upper and lower bands). When all of the data fall inside the uncertainty band and the average difference between the upper and lower bands is nearly zero, the best outcome is achieved. The power of model calibration is demonstrated by the values of the P-factor and R-factor, similar to R^2 and NS. Typically, inverse modeling reduces optimization problems by minimizing the objective function to estimate a vector of unknown parameters. It is suggested that the NS objective function or bR^2 (φ) be used to compare the measured and estimated monthly flow to recalibrate the flow in sufi-2. This measure of efficiency was supplied by (Krause, Boyle and Bäse, 2005).

$$\varphi = \begin{cases} |b|R^2 & \text{for } |b| \leq 1 \\ |b|^{-1}R^2 & \text{for } |b| > 1 \end{cases} \quad (4)$$

where, b is the regression line's slope and R^2 is the coefficient of determination between two simulated and measured signals. While the NS function fluctuates between a large negative value and 1, the φ function's value fluctuates between 0 and 1. Stated differently, a station that can be utilized in the ideal process is associated with a large negative value that indicates improper simulation. to function well in additional simulations (Faramarzi *et al*., 2009). If the calibration is for two variables or the calibration is for discharge simultaneously for several hydrometric stations in the basin, the objective function is defined as follows.

$$g = \sum_{i=1}^{n} W_t \, \varphi_t \quad (5)$$

where, W is the weight of each variable. Another equation used in this context is the NS equation, which is as follows:

$$NS = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (6)$$

where, n is the number of observations, O_i and Pi are the corresponding observed and predicted values, $\bar{O}$ is also the mathematical average of the observed values. Its value varies from negative infinity to 1 and indicates the degree to which the regression line between observed and predicted values aligns with a line having a 1:1 slope.

3. Results and discussions

The SWAT is a semi-physical and semi-distributed hydrological model and, with the ability to be implemented in a GIS environment, is a suitable tool in soil and water studies. This model has been used in different countries to simulate hydrological components. The model's ability to simulate complex hydrological processes of watersheds in a GIS environment distinguishes this model from integrated models in which larger working units are the basis of action. (Akbari Nodehi and Karimi, 2024). The results of this study reveal the successful application of the SWAT model in simulating sediment discharge and streamflow dynamics in the upstream of the Ahar Chai basin, located in northwestern Iran. The model was calibrated and validated with observed data, demonstrating its capacity to accurately predict hydrological processes in a region characterized by complex topography, high variability in precipitation, and semi-arid conditions. Table 1 demonstrates an overview of the Ahar Chai catchment area's characteristics as simulated by SWAT software.

Table 1. Hydrological and geographical characteristics of the upper Ahar Chai watershed.

Parameter	Amount	Parameter	Amount, m
Area of the catchment area	846/65 km^2	Maximum height	2933
Number of sub-basins	52	Minimum height	1460
Number of hydrological units	622 (HRU units)	Height difference	1473

The elevation of the basin is influenced by a diversity of elements such as temperature, precipitation type, evaporation and transpiration, and rainfall. As altitude increases, the rate of precipitation frequently rises and deforms from rain to snow. Consequently, the highest basins typically generate tremendously more sediment than lower elevation basins under identical rainfall situations, because of decreased temperatures and slower evaporation rates at higher elevations. The classification of the elevation levels is illustrated in Fig.4.

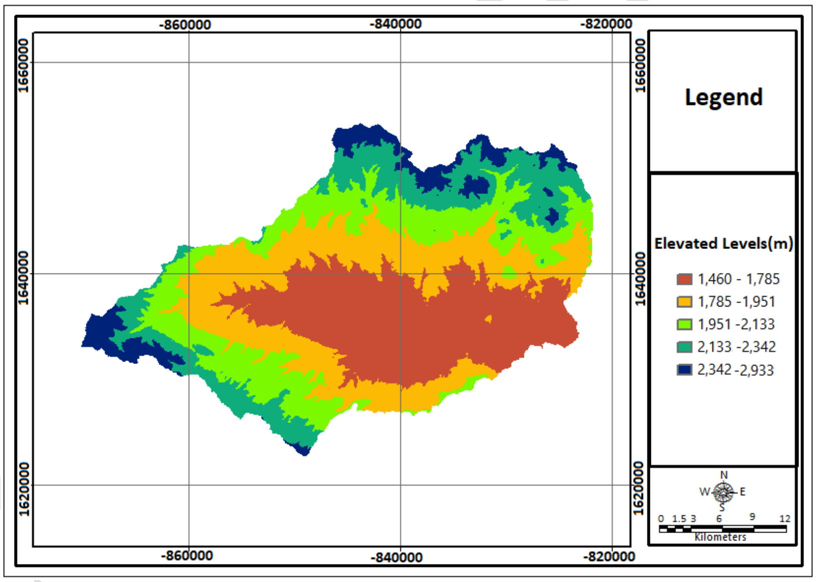


Fig. 4. Altitude classification map of the Ahar chai watershed.

The slope is one of the basic parameters expressing the physical characteristics of the basin. Slope classification by combining other layers including land use and soil maps, makes SWAT generate HRUs in each sub-basin. The variation of slope in this sub-basin is shown in Table 2 and Fig. 5. Based on the findings indicated in this section, the research basin has been divided into 52 sub-basins, as presented in Fig. 6. Land use, soil, and slope maps were taken into the model to determine the HRU components in the following simulation phase. These three essential maps were inputted into the model using the same raster formats and pixel sizes. While the soil and land use maps were prepared in advance and manually entered into the model, the slope map was defined using the DEM map on five levels. As a result of this process, the basin has been divided into 622 HRU units.

3.1. Initial implementation of the model

For this study, the simulation period of 1994-2015 was selected based on monthly flow and sediment discharge data from the basin. Due to gaps and insufficiencies in the sediment data, a sediment measurement curve was developed using available information. The relationship between this curve and the expected sediment amount was used to estimate sediment quantities for various flow rates. Fig. 7 illustrates the relationship between sediment discharge and streamflow in the Ahar Chai river at the Orang station. The graph reveals a significant correlation between the two variables, with a coefficient of determination (R^2) of 0.76. This sediment-discharge curve can be utilized to estimate sediment concentrations corresponding to varying discharge levels across the range of observed values.

Table 2. Distribution of area percentage by slope classification.

Slope class, %	Description	Area coverage, %
0-5	Flat	14.10
5-10	Gently sloping	24.46
10-20	Sloping	35.65
20-40	Steep	22.75
40-9999	Very Steep	3.04

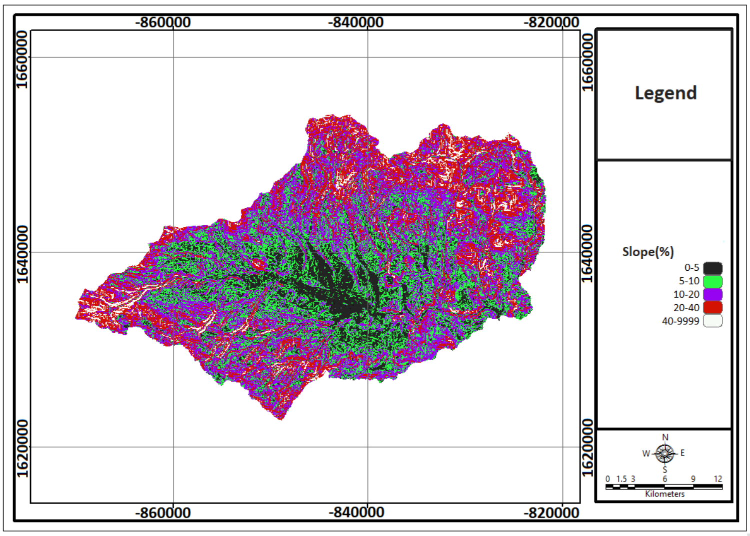


Fig. 5. Topographic slope map of the Ahar Chai watershed.

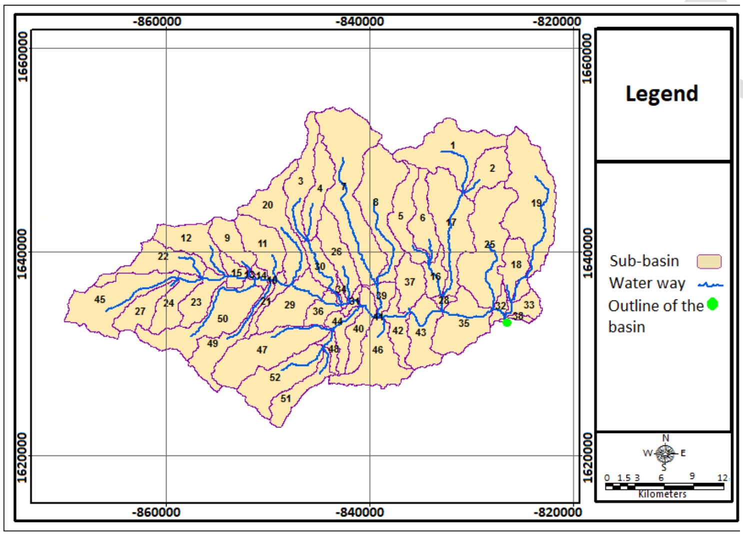


Fig. 6. Geographic representation of sub-basins and hydrological networks delineated by the SWAT model.

3.2. Sensitivity analysis

Following the SWAT model's watershed simulation, the sufi-2 program and SWAT-CUP software were utilized for validation and calibration. The Table 3 displays the optimal results of calibration and validation in the SWAT-CUP software, accounting for the final value obtained during the calibration and validation stage as well as the minimum and maximum range of parameters.

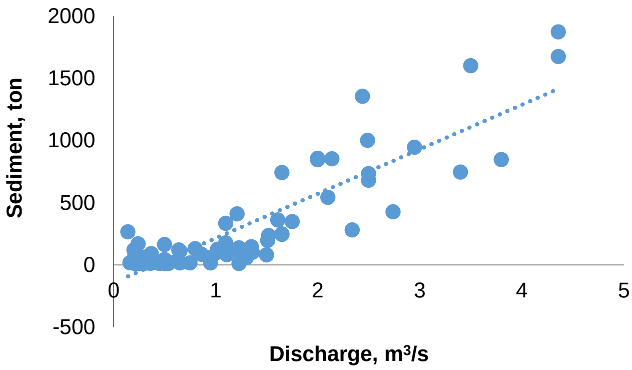


Fig. 7. Correlation between water discharge and sediment discharge of the Ahar Chai river at the orang station.

Table 3. Final parameter values obtained during the calibration and validation stages of the SWAT-CUP software.

Parameter Name	Parameter definition	Minimum parameter value	Maximum parameter value	Calibration	Validation
V_SMFMN	Minimum melt factor for snow (mm/d)	0/2413	0/9246	0/5830	0/6127
V_SMFMX	Maximum melt factor for snow (mm/d)	0/5717	1/5157	1/0437	0/9281
V_ALPHA_BNK	Groundwater base flow coefficient	0/2382	0/4127	0/3255	0/2862
V_SFTMP	Precipitation threshold temperature	2/1073	5/3239	3/7156	2/8714
V_CN2	SCS curve number under moisture	78/5538	85/6661	80/9300	79/2669

	condition II				
V_CH_N2	Main channel Manning's roughness coefficient	0/1582	0/1748	0/1522	0/1678
V_GW_REVAP	The factor related to the transfer of water from the underground water table to the root zone	-223/5574	-207/2488	-214/4031	-222/7417
V_SLSUBBSN	Average slope length	-102/6006	-67/5243	-85/062	-94/2165
V_SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing	1/3561	1/3920	1/3740	1/3734
V_CH_COV2	Chanel cover factor	0/2287	0/2503	0/2395	0/2390
V_TIMP	Snow pack temperature lag factor	0/5430	0/8144	0/6287	0/7965
V_HRU_SLP	Average slope steepness	331/2987	393/9512	362/6250	336/3293
V_SPCON	Linear factor for channel sediment routing	0/0006	0/0015	0/0010	0/0007
V_ESCO	Soil evaporation compensation factor	0/7021	0/9066	0/8043	0/8781
V_CH_COV1	Channel erodibility factor	0/1318	0/1436	0/1377	0/1317

3.3. The results of the Ahar Chai river sediment simulation

Below are the graphical representations from the SWAT model's evaluation criteria as well as the uncertainty analysis, and calibration of the monthly sediment of the Orang hydrometric station to illustrate the visual comparison.Fig.8 demonstrates the observed, best estimation sediment yield, and 95% model prediction uncertainty band. The graphs compare the observational data and the best simulation, and the green band shows the uncertainty of the model, so the smaller bandwidth, means that the model is a more suitable estimate of the observational data. In the figures below, in most parts of the base current, this band has a smaller width and as a result, a more suitable estimate, and in the part of the peak currents, the thickness of the band increases, but in general, it is in good agreement with the trend of the observed measured data.

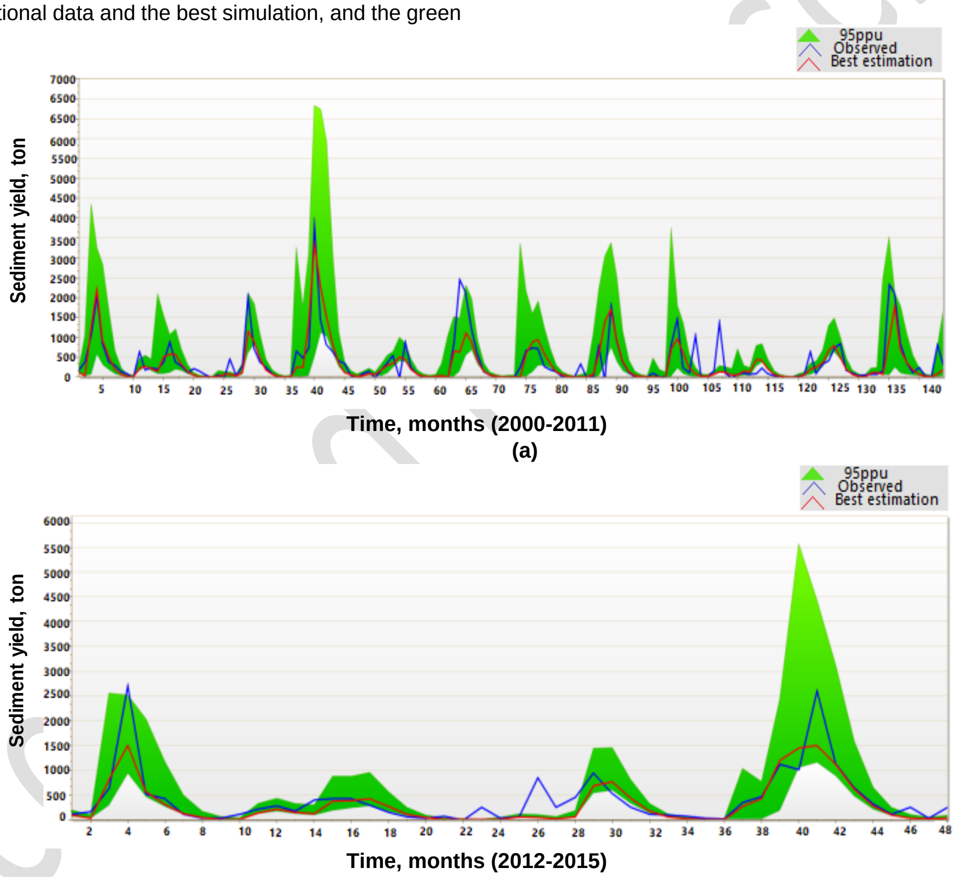
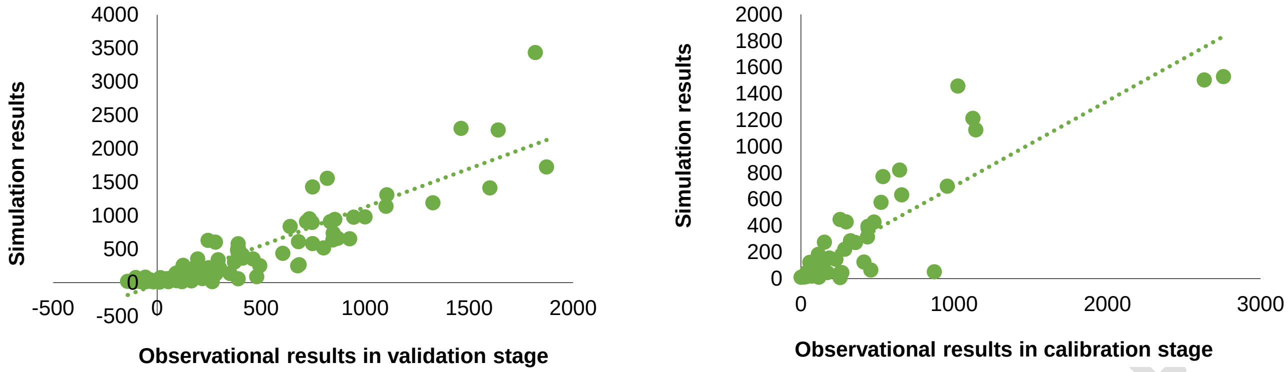


Fig. 8. Comparison of observed and simulated sediment levels, (a) calibration using SWAT-CUP software for the years 2000–2011, (b) validation for the years 2012–2015.

Fig. 9 shows the regression diagram of the simulated and observed sediment data in the calibration and validation stages, the R^2 obtained from these relationships is 0.81 and 0.74, respectively. which indicates the capability of simulating Ahar Chai runoff by SWAT model.

Table 4 illustrating the results of the sediment validation and calibration figures, provides some significant criteria for assessing the model's efficiency. As the presented results in validation and calibration charts which were R^2 and NS criteria had acceptable values during their estimated period, it is approximately approved that the SWAT model has been successful. Some parameters like the monthly sedimentation of the Ahar Chai watershed during the calibration and validation period, should be simulated carefully and accurately; However, in certain situations of overloaded sediment transport such as discharge, the simulation of the basic sediment values was not completely accurate because of lack of sufficient observation data in sediment measurement station in watershed basins.



(a) (b)

Fig. 9. Regression analysis of sediment data, (a) calibration stage, (b) validation stage.

These results are consistent with similar studies conducted in other mountainous and semi-arid regions. For instance, in studies by (Tootle, Piechota and Singh, 2005), SWAT also demonstrated reliable performance in simulating streamflow and sediment transport in regions with similar climatic and topographic characteristics. The validation results are comparable to those observed in other research, such as in the studies by (Gassman *et al*., 2007), which reported similar performance in regions with complex hydrological systems. However, slight discrepancies in the sediment yield predictions between our study and others, particularly in terms of peak sediment discharge events, suggest that local conditions—such as land use, soil types, and vegetation cover—play a significant role in the model's output and may require additional parameter adjustments.

Table 4. Evaluation results of monthly flow sediment model: calibration and validation stages.

Evaluation stages	P-factor	R-factor	R^2	NS
Calibration	0/67	1/34	0/81	0/66
Validation	0/65	1/11	074	0/71

The SWAT model successfully simulated the temporal and spatial distribution of sediment yield within the basin. The results indicated significant variation in sediment production across different sub-basins, with the highest sediment yields occurring in areas with steep slopes and intensive agricultural land use. This finding is consistent with the results of similar studies (Abedini and Tulabi, 2018; Papakonstantis *et al*., 2011), which highlighted the role of topography and land management practices in influencing sediment transport in mountainous basins. However, our study found that areas with dense vegetation cover experienced relatively lower sediment yields, suggesting that land cover change, particularly afforestation or reforestation efforts, may reduce sediment mobilization in the region. Additionally, the results highlight the importance of accurate input data for model calibration and validation, as discrepancies between simulated and observed sediment yields, particularly during peak events, point to the need for more detailed input data, such as high-resolution soil maps and accurate land-use classifications. This issue identifies the influence of input data quality on the model's accuracy, particularly in mountainous regions with high spatial variability.

4. Conclusions

This article's goal is to calculate the upper Ahar Chai basin's sediment load using the SWAT model. The Ahar Chai river, located in northern East Azarbaijan Province, flows eastward and joins the Aras river after merging with the Qarasu river. The model has successfully simulated sediment values in the upper Ahar Chai watershed, as evidenced by the evaluated criteria and coefficients, with calculated values closely matching observed values. The Nash-Sutcliffe coefficient was used to estimate the upper Ahar Chai basin sediment during calibration and validation stages, yielding values of 0.66 and 0.71, respectively. These NS values demonstrate the model's satisfactory performance. The efficacy of the SWAT model in simulating the sediment values of the Ahar Chai basin is demonstrated by the values of the coefficient of explanation (R^2) in estimating the sediment of the basin during the calibration and validation stages, which were equal to 0.81 and 0.74, respectively. The results of this study confirm the SWAT model's potential as an effective tool for simulating sediment yield and streamflow dynamics in the Ahar Chai basin and similar mountainous regions. The model's calibration and validation processes demonstrated good performance in predicting hydrological processes, with results consistent with those of other studies conducted in regions with similar topographic and climatic conditions. Based on the study's findings, it is recommended that further research be done on other processes that the SWAT model can simulate, like water quality or the potential consequences of land use and climate change in the future. Additionally, future research should focus on enhancing model inputs, particularly through the integration of more detailed remote sensing data for land use and soil characteristics and advanced climate modeling techniques. Despite the promising results, several limitations were identified. First, the accuracy of sediment yield predictions was somewhat limited by the resolution of the input data, particularly concerning land-use mapping and soil properties. Furthermore, uncertainties in meteorological data, such as incomplete or inconsistent rainfall records, challenged the model's calibration process. These shortcomings highlight the need for high-quality, site-specific data to improve model accuracy. In conclusion, this study demonstrates the significant potential of the SWAT model as a predictive tool for sediment discharge in the Ahar Chai basin and similar regions.

Author's Contribution

Anis Shafinezhad: Conceptualization, data curation, investigation, methodology, writing–original draft, wriing- review & editing software, validation, visualization, formal analysis.
Yousef Hasanzadeh: Project administration, supervision.
Sayed Saeed Rasinezami: Project administration, supervision, writing–review & editing.

Conflict of Interest

The authors declare that none of the work reported in this paper could have been influenced by any known competing financial interests or personal relationships and no conflict of interest.

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Data Availability Statement

Data will be available on request due to privacy and ethical restrictions.

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