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Estimation of Suspended Sediment Loads in Diyala River Watershed, Iraq, using SWAT Model

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Keywords:
Diyala river watershed; Hemren and Derbendikhan dams; Hydrological modeling; Suspended sediment loads; SWAT model.

Highlights:

- *Estimation of suspended sediment loads from the Diyala River watershed, Iraq.*
- *Application of SWAT model in watershed areas, Iraq.*
- *Calibration and validation of SWAT model using SWAT-CUP and Sufi-2.*

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Abstract: Suspended sediment loads (SSL) transported from the watershed of the Diyala River (WODR) are the most important and dangerous forms of sediment as they drift to the stream flow of the Diyala River and are then transferred to the reservoirs of Hemren Dam (HD) and Derbendikhan Dam (DD), which are located in the study area, affecting the capacity storage of the reservoirs and reducing electrical energy production. Therefore, it is necessary to apply a hydrological model that can simulate the SSL distribution in the WODR to enable decision-makers to develop an appropriate plan to solve the sediment problem. In WODR, the data of SSL are very rare, as sediment measurements have not been conducted for more than 40 years. Due to the lack of historical data for sediment values for the study area and the need to reduce uncertainty, sediment measurements were conducted from November 2022 to April 2023. The motivation of the present study is to study and address the limitations imposed on the Soil and Water Assessment Tool (SWAT) model during the estimation of SSL in the WODR that have scarce data and whose quality is inaccurate. The observed monthly flow data from two gauging stations, HD and DD, from January 2000 to April 2023 and suspended sediment concentration, which was measured in the field from November 2022 to April 2023, were used for calibration and validation of the model, respectively, using the Sequential Uncertainty Fitting Version 2 (SUFI-2) algorithm and SWAT-Calibration Uncertainty Procedures (CUP). Statistically, using the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), and percent of bias (Pbias) the performance of the model was evaluated, with good agreement between observed and simulated values for both stream flow and SSL. The results showed that the values of the SSL in the WODR from January 2000 to April 2023 were equal to 115.240 t/ha/yr. Sub-basins 5 and 12 have the highest SSL values of 15.125 t/ha/yr and 9.098 t/ha/yr, respectively, and the most important factor in SSL formation is the slope of the land, with a correlation coefficient (R^2=0.94).

تقدير أحمال الرواسب العالقة في مستجمعات مياه نهر ديالى، العراق باستخدام نموذج SWAT

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الخلاصة

تعد أحمال الرواسب العالقة (SSL) المنقولة من مستجمعات مياه نهر ديالى (WODR) من أهم وأخطر أشكال الرواسب حيث تنجرف إلى مجرى نهر ديالى ومن ثم يتم نقلها إلى خزاني سد حمرين (HD) وسد دربندخان (DD) الواقعين في منطقة الدراسة مما يؤثر على سعة تخزين الخزانات ويقلل إنتاج الطاقة الكهربائية. لذلك فمن الضروري تطبيق نموذج هيدرولوجي يمكنه محاكاة توزيع SSL في WODR لتمكين متخذي القرار من وضع خطة مناسبة لحل مشكلة تكوين الرواسب. في WODR، تعد بيانات SSL نادرة جدًا، حيث لم يتم إجراء قياسات الرواسب منذ أكثر من ٤٠ عامًا ونظرًا لعدم وجود بيانات تاريخية لقيم الرواسب لمنطقة الدراسة والحاجة إلى تقليل عدم اليقين، تم قياس الرواسب في الفترة من تشرين الاول ٢٠٢٢ إلى نيسان ٢٠٢٣. الدافع وراء هذه الدراسة هو دراسة ومعالجة القيود المفروضة على نموذج اداة تقييم التربة والمياه (SWAT) أثناء تقدير SSL في WODR التي تحتوي على بيانات نادرة والتي تكون جودتها غير دقيقة. تم استخدام بيانات التدفق الشهري المرصودة من محطتي قياس، HD وDD، من يناير ٢٠٠٠ إلى أبريل ٢٠٢٣ وتركيز الرواسب المعلقة، التي تم قياسها في الميدان من تشرين الاول ٢٠٢٢ إلى نيسان ٢٠٢٣، لمعايرة النموذج والتحقق من صحته، على التوالي. باستخدام خوارزمية عدم اليقين المتسلسل الإصدار ٢ (SUFI-2) وبرنامج المعايرة وعدم اليقين SWAT-CUP. إحصائيا، باستخدام معامل التحديد (R^2)، وكفاءة ناش-ساتكليف (NSE)، ونسبة التحيز (Pbias) تم تقييم أداء النموذج، وتم الحصول على توافق جيد بين القيم المرصودة والمحاكاة لكل من تدفق التيار وSSL. أظهرت النتائج أن قيم SSL في WODR من كانون الثاني ٢٠٠٠ إلى نيسان ٢٠٢٣ تساوي ١١٥,٢٤٠ طن/هكتار/سنة. يتمتع الحوضان الفرعيان ٥ و١٢ بأعلى قيم SSL حيث تبلغ ١٥,١٢٥ طن/هكتار/سنة و٩,٠٩٨ طن/هكتار/سنة، على التوالي، والعامل الأكثر أهمية في تكوين SSL هو انحدار الأرض، مع معامل الارتباط (R^2= 0.94).

الكلمات الدالة: جابية نهر ديالى، سد حمرين ودربندخان، النمذجة الهايدرولوجية، احمال الرواسب العالقة، نموذج سوات.

1.INTRODUCTION

A major part of the sediment in the rivers is suspended sediment loads (SSL), which constitute 70 % to 90 % of the total sediment loads of the river [1]. When rain falls in large quantities, it results in dredging tons of soil from the watershed area to the rivers, which in turn is transferred to the reservoirs of dams in the region, which poses a threat to the capacity storage of dams and pumping stations when creating hydroelectric power [2]. Some studies have shown that reservoirs lose about 1 % to 2 % of their volume annually due to sedimentation [3], also removing sediment from reservoirs is an expensive process and has a serious environmental impact [4]. Estimating the SSL in a watershed is important to assess siltation in reservoirs [5], identify sediment source areas [2], and the relationship between land use land cover (LULC) with sediment yield [6]. There are many studies used hydrological models for modeling sediment yield in Tigris River watersheds one of the most important studies is presented in [7], which found that the amount of total sediment yield generated for the period from 1984 to 2013 ranged from (0.028 to 7.4) t/ha/yr using the Soil and Water Assessment Tool (SWAT) model; however, these quantities have not been verified due to the lack of field tests. The value of SSL in the lower part of the Diyala River stream was estimated using field tests as 0.42 t/ha for the period between June 1984 and May 1985 [8]. Others applied the SWAT model to forecast the sediment yield that enters the Dam of Mosul reservoir from the left bank, and they are finding that the total sediment that comes to the reservoir is 14.753 million tons from 1988 to 2008 [9]. The amount of sediment that got into the Dokan reservoir in Iraq, which had an area of 11,690 km², was estimated using the SWAT model from 1959 to 2013. The results of the study show that the total sediment loads reaching this reservoir were about 72 million m³ [5]. The SSL was estimated using a SWAT model with an artificial neural network (ANN) in the watershed of Al-Adhaim in Iraq, which had an area of 11217 km², from 1985 to 2013. The study clarified that the total amount of SSL was 112 million tons from 2001 to 2013 [4]. Therefore, it is necessary to find a hydrological model that can be used to overcome the problem of the lack of data required to calibrate and validate the resultants, which leads to minimizing input uncertainty during the calibration of the model and thus to potential errors [10], and among the most important of these programs is the SWAT model. SWAT is a physically based and close to distributed model; also, the time step is continuous [11], and it needs data on the weather, soil classifications, land topography, and LULC in the catchment area that is studied. It is distinguished by its ability to obtain easily available global data with high computational efficiency and less time and cost [12]. It was used in all countries of the world to simulate sediment yield in the watershed [13], hydrological components [14], the effect of LULC on the water resources [15-17], and the effect of climate change on the water resources [18, 19]. The aim of this study is to use the SWAT model to calculate the SSL for the WODR and provide an indication of their temporal and spatial distribution from January 2000 to April 2023. This study is considered the first of its kind in the region to estimate SSL based on measured of suspended sediment concentration in the Diyala River that income from the WODR for purposes of calibration and verification the results of the SWAT model. This study helps encourage the development of a sediment monitoring program for the region at more than one site due to the need to establish sediment production time series to calibrate SWAT model parameters and reduce uncertainty.

2.STUDY AREA

WODR is located within the Iranian and Iraqi borders [8]; it constitutes 41 % of Iraqi territory and 59 % of Iranian territory. It is located between latitudes 33.95 N and 35.83 N and 44.5 E and 47.83 E and extends to an area of 25652 km². The Diyala River, which is formed from the WODR, originates from the Iranian side and empties into the Tigris River inside Iraqi territory [7]. There are two streamflow measurement stations in the study area: the first at Derbendikhan Dam (DD) in the upper part of the river and the second at Hemren Dam (HD) in the lower part of the river as shown in Fig. 1. The average area's elevation is 1699 m above sea water level. Most of the surface water is stored in the two reservoirs of the HD and DD, so the rainy season extends from November to May, followed by a dry season. The average annual rainfall is 325 mm and the temperature 22 °C, from 1996 to 2022.

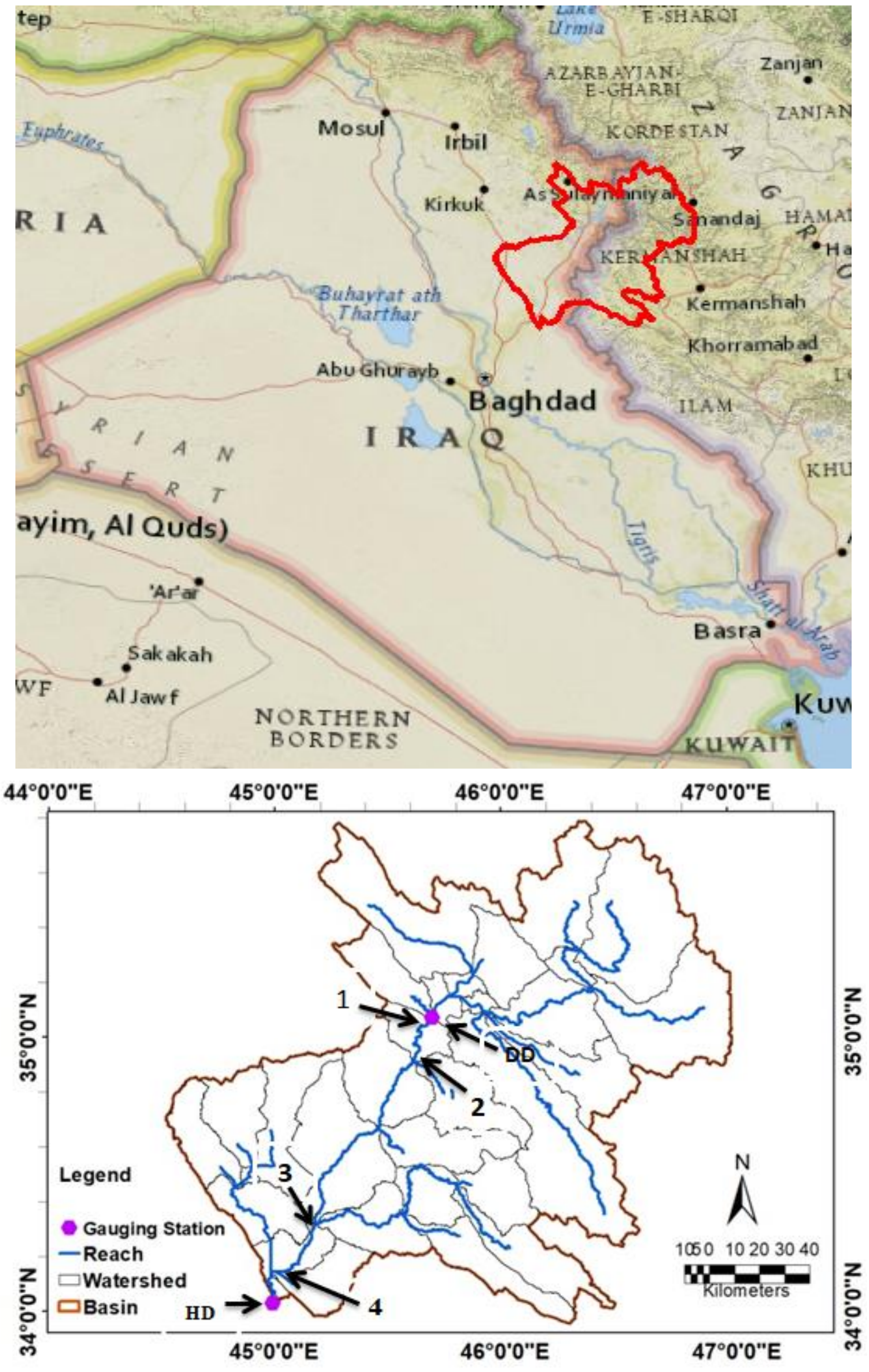

Fig. 1 Map of the WODR.

3.METHODOLOGY

In the present study, the SSL in the WODR was simulated for the period from 1996 to April 2023, as follows:

1- The model ran from January 1996 to April 2023.
2- The streamflow was calibrated from 2000 to December 2015 and validated from 2016 to April 2023 for each gauging station at HD and DD.
3- Field measurements were conducted to measure the suspended sediment concentration in the stream river that passes through sub-basin 29 and sub-basin 13 from November 2022 to April 2023.
4- The amount of SSL was estimated, and spatial distribution analysis was performed for it in the WODR from January 2000 to April 2023.

4.INPUT DATA

The digital elevation model (DEM) with (30×30) m resolution for the study area, which was taken from the Shuttle Radar Topography Mission (SRTM),that was downloaded from the site (http://earthexplorer.usgs.gov/) on 15 October 2021,was used for delineation of the watershed, streamflow extraction, slope, and dividing the watershed into sub-basins. The entered data is displayed on the global coordinate system, which is georeferenced to the World Geodetic System (WGS84) and Universal Transverse Mercator (UTM) for zone 38 N, as shown in Fig. 2 (a). The soil map data supplied by the Food Agricultural Organization (FAO) was used to carry out the SWAT model and is available in the form of a scale vector of 1:500,000. The map of soil used was downloaded from the site (https://www.fao.org) on 25 September 2021 as shown in Fig. 2 (b); the types of soil common are loam, clay loam, and clay which appear in Table 1. The LULC 2020 map in 20 September 2020 was gained from satellite Landsat 8 with a spatial resolution 30 m and downloaded from the site (https://erthexplorer.usgs.gov) then classified into five types: Agricultural land generic (AGRL) by 0.37 %, Shrub land (RNGB) by 2.02 %, settlement areas (URBN) by 5.21 %, Water (WATR) by 0.87 %, and Barren land (BARR) with 91.53 %, as shown in Fig. 2 (c). Supervised classification was used to classify the classes of LULC for the image of the Landsat 8 satellite. There are four categories of land slopes for hydrologic response units they are 5-10, 10-20, below 5, above 20 %, Fig. 2 (d). The daily weather data used in the SWAT model, such as solar radiation, wind speed, maximum and minimum temperature, precipitation, and relative humidity, from three metrological stations located in the study area were obtained from the (Bureau of Meteorology, Iraq, 2022, unpublished data), and the locations of the meteorological stations are listed in Table 2. The daily streamflow data was obtained at HD and DD from 1996 to April 2023 (Management of Hemren and Derbendikhan Dams, Iraq, 2022, unpublished data). There is no recorded data on the amount of SSL for the study area, so field measurements were conducted to measure the suspended sediment from November 2022 to April 2023 in the Diyala River that passes through sub-basins 13 and 29 in 1, 2,3, and 4, as shown in Fig. 1. The concept of sensitivity analysis refers to the process of determining the rate at which the output of a model changes as a result of a change in its inputs (parameters); as a result, it provides a picture of the sensitivity of the parameters and is essential for model calibration [20]. When analyzing the sensitivity, the parameters that are considered insensitive will be eliminated, consequently, the number of parameters will be reduced when performing the calibration procedure for the model. There are two paths to sensitivity analysis: global sensitivity analysis, where a set of parameters is changed simultaneously; this is the best way to determine the linkage between the parameters; and one-at-a-time sensitivity analysis, where one parameter is changed at a time [21]. Calibration was carried out using the SWAT Calibration and Uncertainty Procedures (CUP) program with Sequential Uncertainty Fitting Version 2 (Sufi-2) for the SSL and streamflow following the methodology in [21, 22]. For the suspended sediment, the results of the model have been calibrated and validated from November 2022 to April 2023 at sub-basin 29 in (3 and 4) and sub-basin 13 in (1 and 2) respectively, for every 15 days as a time step, while for the streamflow the calibration was carried out from January 2000 to December 2015 and the validation from January 2016 to April 2023 for a monthly time step at the gauging stations in HD and DD. Using Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2), and percent bias (Pbias) [23], the performance of the model was evaluated statistically according to the recommended general standards in Table 3.

Table 1 Soil Categories in the WODR.

No.	FAO Soil Code Name	Code in Arc SWAT	Soil Type	Area km²
1	3108	I-E-Xk-bc-3108	Loam	140.17
2	3109	I-E-bc-3109	Loam	692.31
3	3122	I-Rc-Xk-c-3122	Loam	12142.78
4	3254	Rc33-3bc-3254	Loam	3.87
5	3276	Vc1-3a-3276	Clay	1983.51
6	3288	Xh31-3a-3288	Clay Loam	189.05
7	3300	Xk28-b-3300	Clay Loam	3135.82
8	3304	Xk5-3ab-3304	Clay Loam	1110.97
9	3312	Xk9-2/3a-3312	Clay Loam	1630.58
10	3324	Yy10-2/3a-3324	Clay	1570.99
11	3603	Yk34-b-3603	Loam	3052.53

Table 2 Meteorological Station in the Study Area.

ID	Name	Latitude	Longitudinal	Elevation (m)
1	Halabja	35.19	45.90	721
2	Sulaymania	34.35	45.39	202
3	Khanaqen	35.53	45.46	883
4	Sannandaj	35.02	46.96	1493

Table 3 Performance Recommended Statistics for Monthly Time Step [24].

Performance Rating	Pbias (%)	R^2	NSE
Very good	Pbias < ±10	$0.8 \leq R^2 \leq 1.0$	0.75 < NSE ≤ 1.00
Good	≤ Pbias < ± 1510 ±	$0.7 \leq R^2 \leq 0.75$	0.65 < NSE ≤ 0.75
Satisfactory	≤ Pbias < ± 2515 ±	$0.5 \leq R^2 \leq 0.6$	0.50 < NSE ≤ 0.65
Unsatisfactory	Pbias > ± 25	R2< 0.5	NSE ≤ 0.50

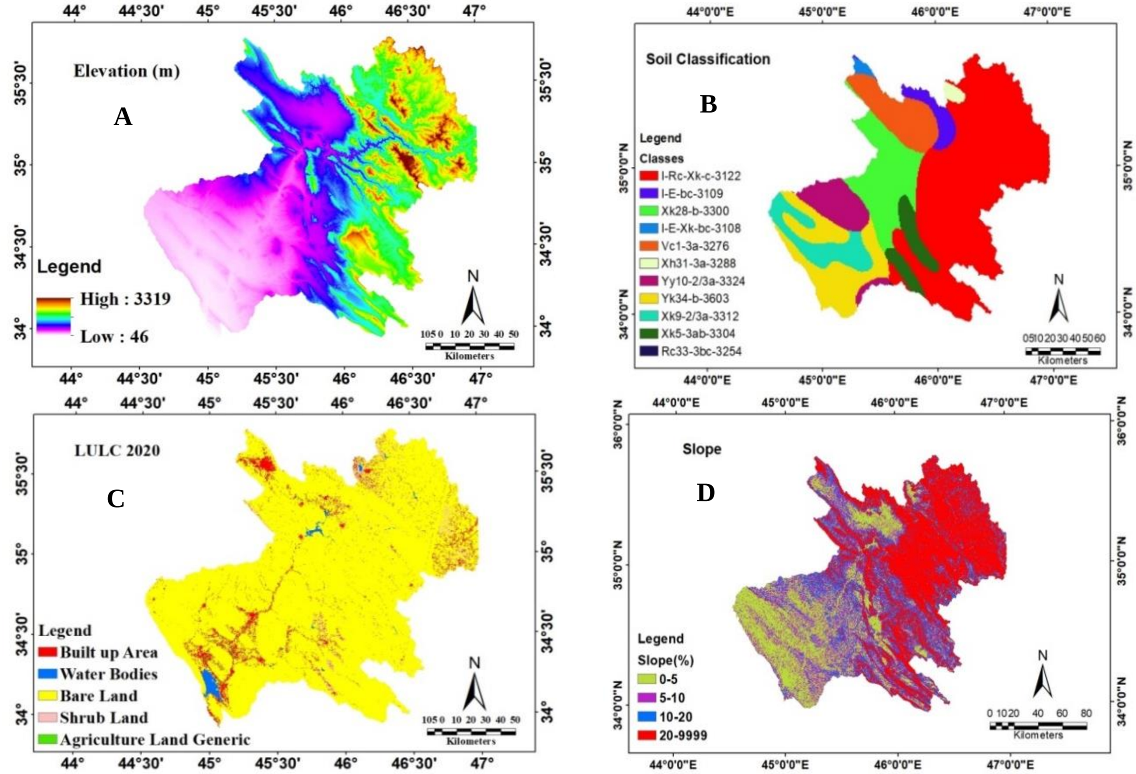

Fig. 2 Information Maps of WODR Used in SWAT Model: (A) Elevation (B) Soil Classification (C) LULC Map in 2020 (D) Slope Land.

5.SWAT MODEL SET UP

The program that was used in the present study is SWAT version 2012. SWAT is a free program that was downloaded from the site https://swat.tamu.edu/, where it was linked with the Geographic Information System (GIS) program through the toolbar. To apply the SWAT model, watershed delineation is necessary to convert basin to sub-basins and then to hydrological response units (HRUs). Thirty three sub-basins have been created while the HRUs are 899 units. Maps of land use, soil texture, and slope were defined until they corresponded to program inputs, then daily weather data was input during the simulation period, at the end SWAT was run with default parameters and read the outputs. The parameters obtained after performing the calibration and validation processes are entered again into the program to get the required results.

6.FIELD MEASUREMENTS

A Sample Collection Device (SCD) was used for sampling suspended sediment, which is a mechanical device specially made to collect water samples from different depths at the same time, its main advantages are ease of use, portability, low cost, and high accuracy. The components of the device are shown in Fig. 3. Suspended sediment samples were taken from the Diyala River at sub-basins 13 and 29 in 1, 2, 3, and 4 after each rainfall event from November 2022 to April 2023. These samples were taken from the middle, quarter, and three-fourths of the width of the river section at 0.2 and 0.8 depth of the river, so the number of samples taken is six along the river section. So, the average was taken for these six points at each time.

6.1.Method of Sampler Assembling

Samples were taken as follows:

1- The depth of the river was measured at the moment the samples were taken, and steel cylinder A (it is possible to install more than one cylinder on the pipe) was fixed on the pipe at the depth required.
2- The SCD was put in the water manually as shown in Fig. 4, at the required station, and withdrawn the steel wire L by the hand handle H to tighten the steel arm C which will open the valve B, at the same moment pull the handle E which air relief via valve E, instantaneously, and allow the filling of container A through the lower orifice B by the vacuumed pressure.
3- The hand handle H was released to allow the steel spring D to return the steel arm C to its previous position and reclose valve B after the container A filling, then leave the handle E to reclose the air opening.
4- The SCD was manually lifted from the water to empty the containers, and samples were collected and labeled.
5- Repeating steps 2 through 4 at the other stations.

The water samples that were taken were filtered using pre-weighed filters with a porosity ranging from 2-3 micrometers in a plastic bottle size of 0.5 liters, and the weight of the sediment suspended in each sample was determined by the weight of the filter after drying in the oven at a temperature of (103-105) °C. For comparison, the device was calibrated by the standard method used in [25], and the perfect correlation appeared between the two methods with (R^2 = 0.91).

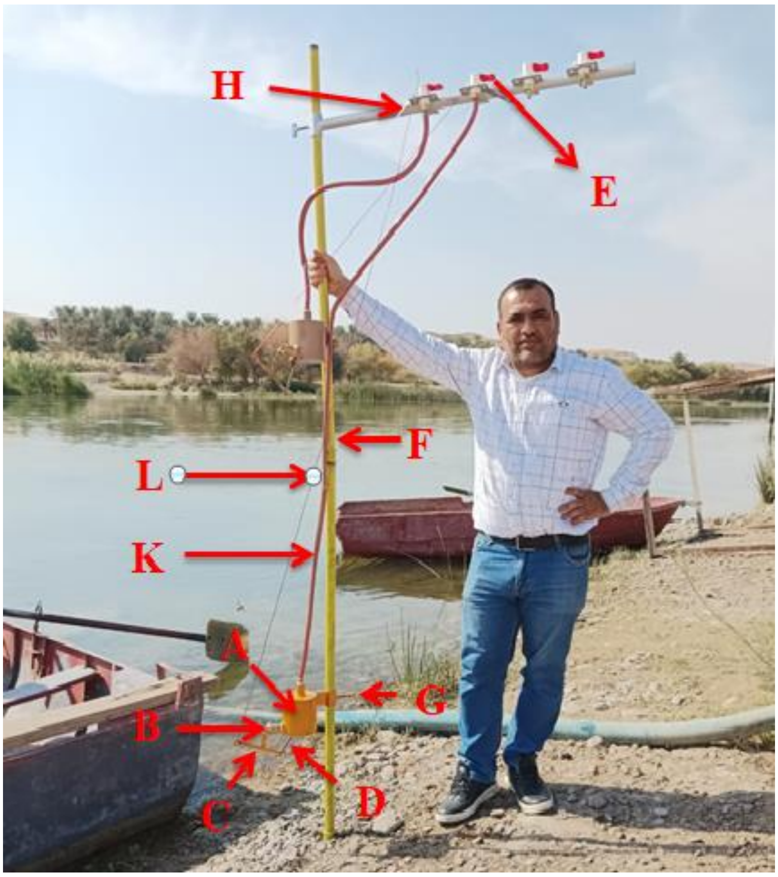

Fig. 3 Shows the Components of SCD: (A) Steel Cylinder Container Painted with Anticorrosion Paint with a Capacity of One Liter; (B) Valve Diameter of 2 cm; (C) Steel Arm 20 cm Long; (D) Steel Spring; (E) Hand Handle; (F) Steel Pipe Diameter of 2.5 cm and Variable Length; (G) Clamp; (H) Hand Handle; (K) Plastic Pipe Linked to the Upper Orifice to Allow the Air Relief Via Valve E; (L)Steel Wire.

Fig. 4 Method of Samples from the Diyala River.

7.RTSULTS

7.1.Sensitivity, Calibration, and Validation Analysis

Sensitivity analysis, calibration, and validation of SWAT model parameters were performed using SWAT-CUP and Sufi-2, which have been applied in many studies [26, 27]. At first, twenty parameters were extracted by sensitivity analysis and from the past studies in [28, 29, 7] with 270 simulations at the first iteration, after conducting four simulations, the most sensitive of these parameters were chosen. About the streamflow, the parameters of the SWAT model in the WODR showed that CN2.mgt, SOL_AWC (...).sol, and ALPHA_BF.gw are the most sensitive parameter values taken in the calibration process, as shown in Table 4. Similarly, sensitivity analyze was conducted for the SSL, and the best sensitivity parameters were extracted from the past studies [4]. It is preferable to first calibrate the streamflow and then move the sediments because sediment is directly affected by surface runoff [20]. The calibration process was conducted at two gauging stations in the WODR at (HD and DD) using initial parameters and the outcomes have been displayed. Then, using SUFI-2 generated automatic calibration, if we get to an acceptable match between observed and simulated values for the flow, the best parameters are copied to the Arc SWAT setup instead of the default parameters, and we run the SWAT model again according to the new parameters. For a streamflow, the calibration and validation were conducted as a monthly time step from January 2000 to December 2015 and from January 2016 to April 2023 in HD station (Fig. 5) and DD station (Fig. 6), respectively. The performance of the SWAT model at the HD shows that the R^2, NSE, and Pbias for the calibration (validation) were equal to 0.79, 0.84, and + 9.7 % (0.86, 0.84, and 7.4 %), respectively, whereas at the DD they were equal to 0.85, 0.86, and 5.8 % (0.87, 0.83 and -2.5 %), respectively. The spatial validation and calibration method can be applied in watersheds whose LULC, climate, and soil properties are similar [2]. For the SSL, the sub-basins 29 and 13 were used for calibration and validation of the results of the SWAT model for the observed suspended sediment concentration from November 2022 to April 2023 Figs. 7, 8. For basins 29 and 13, the statistical summary for the model performance evaluation was highly satisfactory, with a strong correlation between the observed and simulated values based on Table 5. The statistical analysis outcome for streamflow and SSL indicates that the model performance is good and reliable in terms of the acceptable standard recommended according to Table 3.

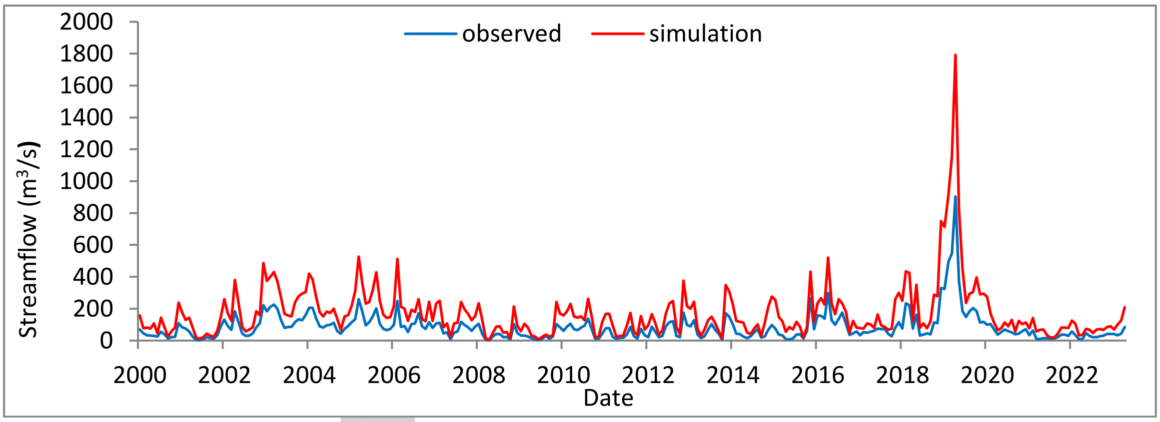

Fig. 5 Calibration and Validation in HD.

Table 4 Sensitivity Parameters for Suspended Sediment and Streamflow.

Process	Parameter name	Description	Initial range Min.	Max	Fitted value
Streamflow	R__CN2.mgt	SCS runoff curve number factor	-0.5	0.5	-0.17
	R__SOL_AWC (..).sol	Available water capacity of the soil layer	-0.3	0.1	0.55
	V__ALPHA_BF.gw	Alpha factor for base flow	0	1	0.65
	V__GW_DELAY.gw	Delay of ground water	30	450	255
	R__ESCO.hru	Factor of soil evaporation	0	1	0.41
	R__GW_REVAP.gw	Groundwater “revap” coefficient	0.02	0.2	0.035
	HRU_SLP.hru	Average slope steepness	0	1	0.65
	R__SLSUBBSN.hru	Average slope length	0	0.02	0.013
Suspended Sediment	SPCON.bsn	The linear parameter for calculating the max. amount of sediment that can be re-entrained during channel sediment routing	0.0001	0.01	0.0003
	USLE_K(..).sol	USLE, equation of soil erodibility (k) factor	0	0.65	0.45
	R__OV_N.hru	Manning’s “n” value for overland flow	-0.3	0.1	0.05
	R__SOL_K(..).sol	Saturated hydraulic conductivity	-0.1	0.35	0.24
	R__SOL_AWC(..).so	Available water capacity of the soil layer	-0.3	0.1	0.55
	R__CH_N2.rte	Manning’s “n” value for the main channel	0	0.21	0.15
	R__CN2.mgt	SCS runoff curve number factor	-0.5	0.5	-0.12
	USLE_P.mgt	USLE, support practice parameter	0	1	0.35
	V_SPEXP.bsn	Exponential Parameter for calculating max. amount of sediment that can be re-entrained during channel sediment routing	1	1.5	1.26
	CH_COV1.rte	Channel erodibility factor	-0.05	0.6	0.3

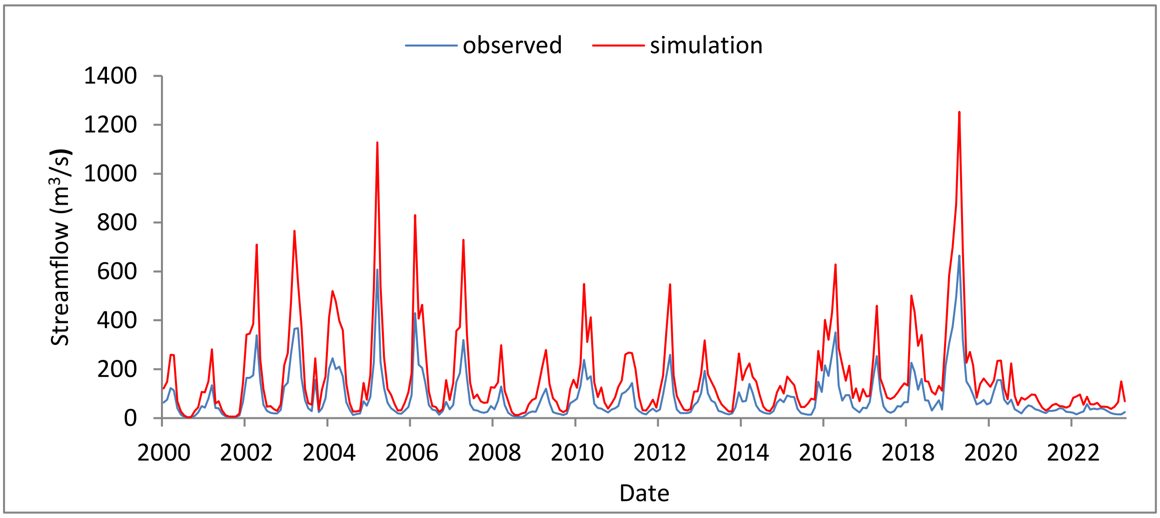

Fig. 6 Calibration and Validation in DD.

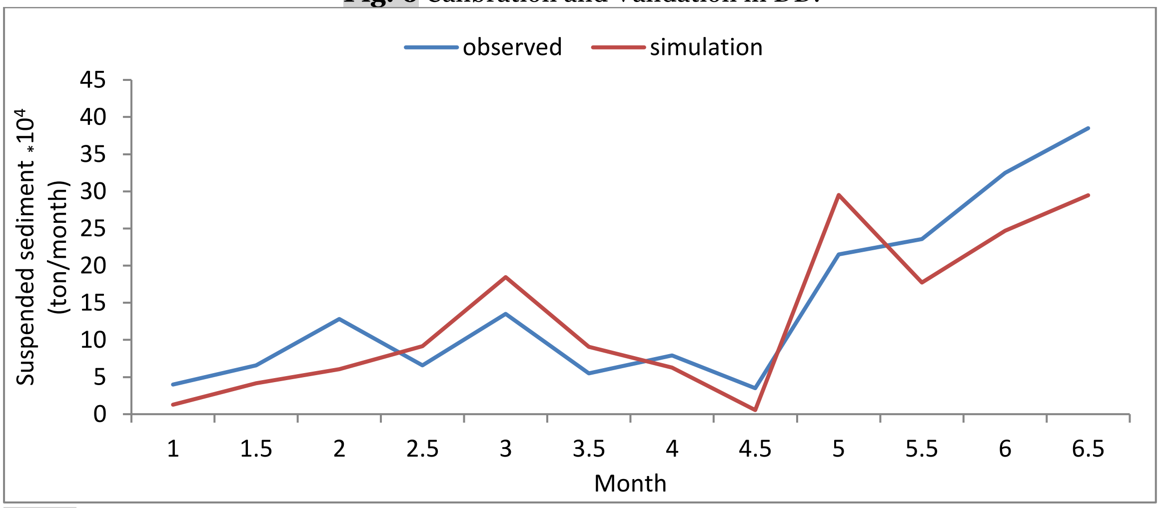

Fig. 7 Calibration Period at Sub-basin 29 between Observed and Simulated SSL (November 2022-April 2023).

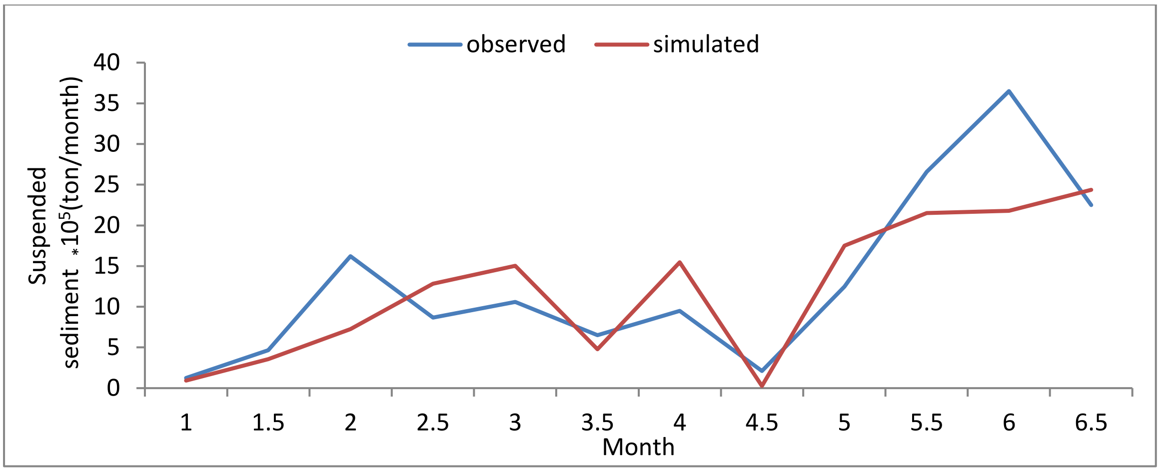

Fig. 8 Validation Period at Sub-basin 13 between Observed and Simulated SSL (November 2022-April 2023).

Table 5 Sensitivity Parameters for the SSL.

Statistical indices	Sub-basin 13	Sub-basin 29
	Validation	Calibration
R^2	0.66	0.78
NSE	0.68	0.75
Pbias	-10.2 %	-11.4 %

7.2. Assessment of Suspended Sediment in the Study Basin

The SSL values of 33 sub-basins in the whole WODR were shown in Fig. 9. The maximum values of SSL were in sub-basins 5 and 12, with values of 15.125 and 9.098 t/ha, respectively, while the lowest values of SSL were in sub-basins 31 and 30, with 0.075 and 0.260 t/h, respectively. We note that the values are close to the study conducted by [7] in the same study area from 1984 to 2013, which showed that the sediment yield values are (0.068 - 7.400) t/ha, except in sub-basin 5, which is due to the high slope land of the sub-basin within 63.9 %. The total SSL in WODR from 2000 to April 2023 with a four-year warm-up period is about 115.247 t/ha, and the annual sediment in the basin was estimated at 4.920 t/ha/yr of which approximately, 12620784 tons of SSL were deposited between January 2000 and April 2023. By comparison of the ten categories of the SSL map in Fig. 10 and the land slope map in Fig. 2 (d), it is evident that some sub-basins have the same land use and soil, but a higher slope yields more SSL; this has been confirmed by researchers in [5]. This behavior is evident in the sub-basins 5, 12, and 14, which have SSL values of 15.125, 9.098, and 6.514 t/ha/yr with land slopes of 63.9, 53, 41 %, respectively, whereas a low land slope produces low SSL values, this behavior appears in sub-basins 31 and 32, which have land slopes of 2.1 and 5 % with SSL values of 0.075 and 0.315 t/ha/yr, respectively. Therefore, the spatial distribution of the map of SSL helps to develop an appropriate vision by decision makers to reduce sediment, especially in areas with high sediment; this treatment may include the construction of a check dam, a riparian forest buffer, filter strips, an infiltration trench, and a sediment basin.

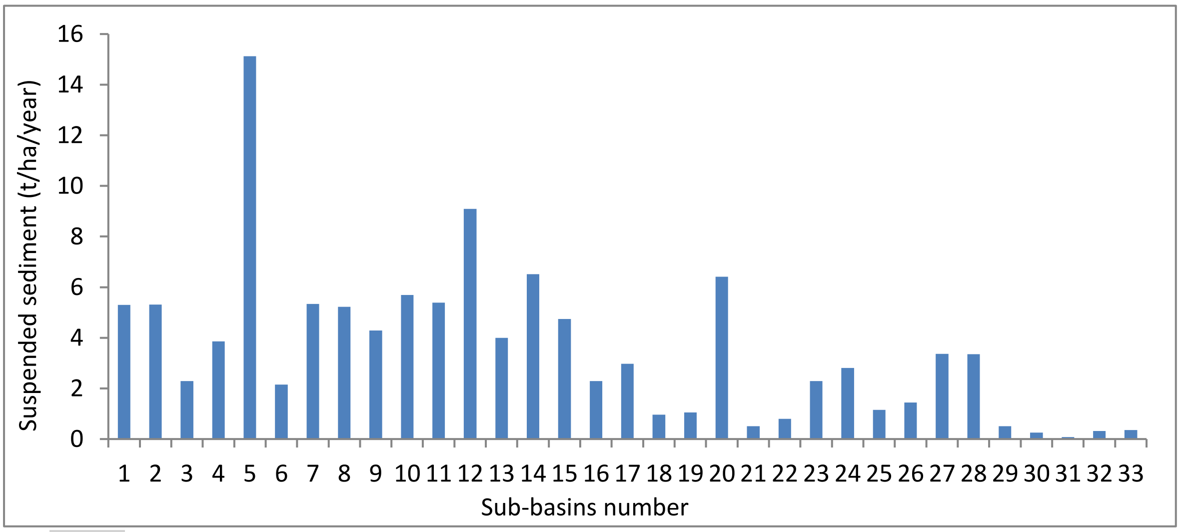

Fig. 9 Average SSL in each of the 33 Sub-basins from 2000 to April 2023 in the Study Area.

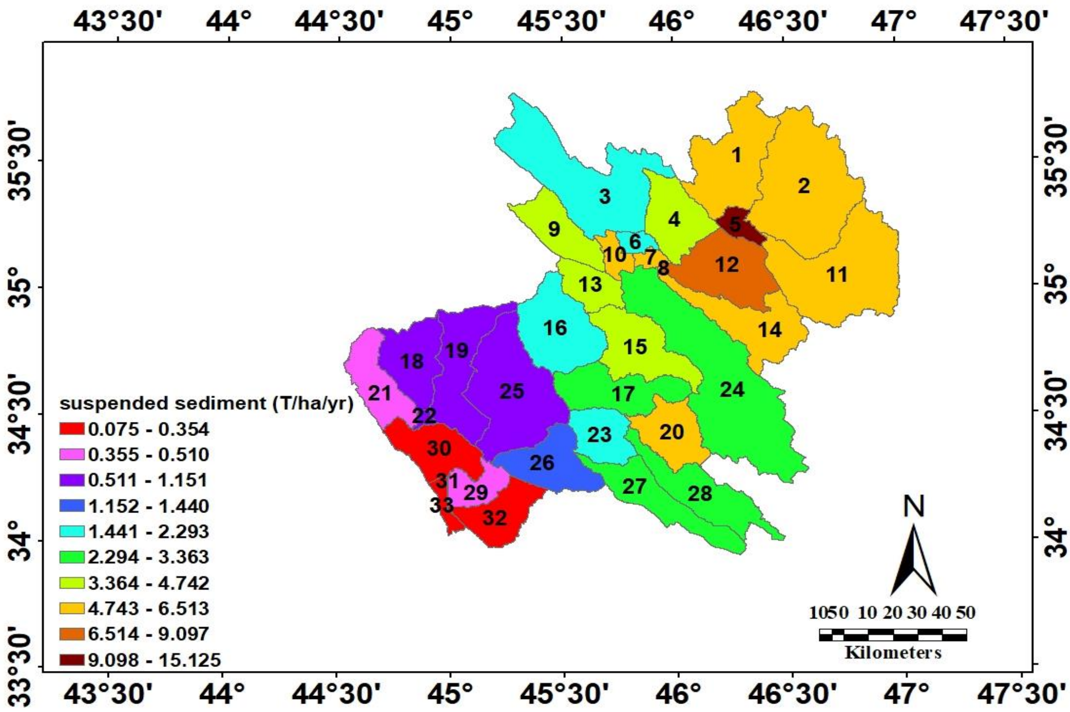

Fig. 10 The SSL of WODR Distribution Spatially.

8.CONCLUSIONS

In the present study, the SWAT model was applied to predict the amount of SSL in WODR from January 2000 to April 2023; the most important conclusions are below:

- It is possible to perform spatial calibration at a gauging station and verify the results at another gauging station within the same watershed area if the calibration time period is short and if the soil, climatic, and land use are similar conditions.
- Most of the SSL come from Iranian territory, where they constitute more than 60 %, which requires intensified efforts to cooperate with the Iranian side to find solutions to reduce the amount of sediment.
- The DEM and LULC map with a spatial resolution of 30 m are considered suitable for conducting SSL simulation when used in the SWAT model while giving satisfactory results during the study period.
- Most of the soil types in the region are loam to clay loam and are soils that produce sediments in large quantities with little vegetation cover, which requires intensified efforts to encourage reforestation, especially in sloping areas, to preserve the soil and prevent erosion.
- There is a strong correlation between the SSL production and the slope, which indicates that the most effective factor in suspended sediment transport from the watershed is the land slope.
- Creating an SSL map in WODR will help decision-makers take the necessary measures to determine the amount of sediment for each sub-basin and thus find appropriate ways to reduce the amount of sediment transported to HD and DD reservoirs. We recommend intensifying the monitoring program to measure sediments along the Diyala River in different locations and involving stakeholders in decision-making before taking any action to reduce sediments.

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NOMENCLATURE

DD	Derbendikhan Dam
DEM	Digital elevation model
GIS	Geographic Information System
HD	Hemren Dam
HRUs	Hydrological response units
LULC	Land use land cover
NSE	Nash-Sutcliffe efficiency
Pbias	Percent of bias
R^2	Coefficient of determination
SCD	Sample Collection Device
SSL	Suspended sediment load
WODR	Watershed of Diyala River

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