JOURNAL OF THE CIVIL ENGINEERING FORUM

Journal of the Civil Engineering Forum, September 2020, 6(3): 247-258
DOI 10.22146/jcef.55298
Available Online at http: https://jurnal.ugm.ac.id/jcef/issue/archive

Modeling Runoff and Sediment Yield in Highly Gullied Regions of Kashmir using SWAT Model: A Case Study of Lolab Watershed

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SUBMITTED07 March 2020**REVISED**02 May 2020**ACCEPTED**18 May 2020

ABSTRACT Soil erosion in highly gullied regions of Kashmir valley is a serious global issue due to its impacts on economic productivity and environmental consequences such as land disintegration and one of the most affected areas is Lolab which is flood-prone and has witnessed several disastrous floods in the past. This means assessment of hydrological behavior should be highly prioritized and the most problematic sub-basins contributing to the erosion and excessive runoff identified to formulate and apply proper management strategies. This study integrated the Soil and Water Assessment Tool (SWAT) with Arc software to simulate the runoff and sediment yield of Lolab Watershed. The method was applied due to its flexibility in inputting data requirements and the capability to model larger catchments and mountainous areas. Meanwhile, sensitivity analysis showed the most sensitive four parameters for runoff estimation with the initial soil conservation service curve number II rated to be the highest and two others were found for sediment estimation with channel erodibility factor rated highest. The calibration of the values of these sensitive parameters led to the provision of reliable Nash-Sutcliffe (N_{SE}) and Coefficient of determination(R^2) efficiencies which makes SWAT a good analyzing tool to assess the hydrological behavior of highly gullied region and un-gauged basins of Kashmir. These factors were found to be above 0.90 for both runoff and sediment yield and the sediment yield rates were estimated using SWAT at individual sub-basin levels after which a prioritization map was prepared to determine the most problematic sub-basins in the watershed.

KEYWORDS Runoff; Sediment Yield; Un-gauged Basins; SWAT; Sensitivity Analysis.

1 INTRODUCTION

Soil erosion has been a long-standing problem throughout the globe with adverse effects on crop productivity and the functioning of civil structures. This has led to the prioritization of watershed management at the grass-root level to limit the disintegration of arable lands and malfunctioning of hydraulic structures (Nikolaidis et al., 2013; Bisantino et al., 2015)). This involves the optimum utilization of watershed resources without compromising the balance between natural resources and the environment (Van Andel, 2010). There are several conventional methods of evaluating soil loss from a watershed but the reliability of their prediction is tedious and time-consuming and this led to the introduction of watershed models which have revolutionized the process of analyzing catchment hydrology by producing reliable output while saving the precious time of decision-makers. These models are divided into three different categories which are empirical, conceptual, and physical. The empirical models analyze the hydrological parameters using the coefficients evaluated from actual observation or measured data (Wheater et al., 1993), conceptual models incorporate a general depiction of the catchment to avoid point by point data necessities and represent catchment as a progression of internal storages (Sorooshian, 1991) while the physical models analyze the entire erosion process by evaluating the individual components from the solution of corresponding equations. They all, however, vary significantly in their analysis of parameters, input and output flexibility, scale accountability, processing ability, computational efficiency, and capability to model the changes in the catchments. There is, therefore, the need to use the appropriate model to predict the runoff and sediment yield from the watershed and identify the most problematic sub-basins for rational utilization of land, soil, and water resources (Himanshu et al., 2017). This is necessary considering the possibility of having one model performing effectively in a certain range of conditions and lacks the capacity to do the same in others. A comprehensive review of models and their global application have shown SWAT, ANSWERS, AGNPS, WEPP, and SHETRAN to be the most capable for prediction and assessment of several hydrological parameters such as runoff and sediment yield and this makes them more reliable to accomplish sustainable watershed management practices (Gull and Shah, 2020). SWAT has been reported to have the advantage of working better in large watersheds and mountainous areas as well as in predicting runoffs (Shen et al., 2009). It performs effectively in hilly areas and serves as a better tool for the general assessment of hydrological parameters (Pradhan et al., 2020). Attempts have been made to predict the runoff and sediment yield of Lolab watershed using a combination of manual and auto-calibrated SWAT models for a different set of time and with low-resolution input data (Gull et al., 2017). SWAT model has also been found to be suitable for best management practices of watersheds and reported to be useful for a wide range of conditions (Zhang et al., 2014).

2 METHODS

Soil and Water Assessment Tool (SWAT) was used in this research due to its ability to predict the impact of land management practices on the hydrology of large complex watersheds. The main focus of the study was to determine the efficiency of the model using a high-resolution input data and comparing its output with the actual runoff and sediment yield values observed in Pohru watershed and the sub-basins identified to have the maximum amount of sediments.

2.1 Model Description

SWAT is a river basin scale and continuous spatially distributed physical watershed model designed to simulate different hydrological parameters in large complex watersheds and also capable of being integrated with GIS interface (Arnold et al, 1998). It creates Hydrologic Response Units to analyze the diversity of a catchment in terms of land use/land cover, soil characteristics, and slope while the movement of water in the channel and overland flow are simulated in the routing and land phases of the model, respectively. The movement of water on the surface was analyzed using the water balance equation provided by Setegn, et al. (2008) as shown in the following Equation (1):

$$SWt = SW0 + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw)x \tag{1}$$

Where, SWt is the final soil water content in millimeters, $SW0$ is the initial soil water content in millimeters, t is time in days, $Rday$ is the precipitation of day x in millimeters, $Qsurf$ is the surface runoff on day x in millimeters, Ea is the evapotranspiration on day x in millimeters, $Wseep$ is water entering the vadose zone on day x in millimeters, and Qgw is the return flow on day x in millimeters.

SWAT has the ability to calculate surface runoff using two methods (Neitsch et al., 2011) and this allows the user to select the most suitable method according to the data and output requirement available. Moreover, the SCS curve number method (SCS, 1985) used in analyzing runoff is presented in Equation (2) as follows:

$$Qsurf = \frac{(Rday - Ia)^2}{(Rday - Ia + S)} \tag{2}$$

Where, *Rday* is the precipitation of day *x* in millimeters, *Ia* is the initial abstractions including surface storage, interception, and infiltration prior to the runoff in millimeters, and *S* is the surface retention in millimeters which depends on the soil water content and calculated using Equation (3).

$$S = 25.4(\frac{1000}{CN}-10 \qquad (3)$$

Where, *CN* is the curve number for the day. The modified version of the Universal Soil Loss Equation (Wischmeier and Smith, 1978) is usually used by SWAT to calculate the sediment drawn from a particular response unit provided in Equation (4) as follows:

$$Tsediment = (Qsurf \times qpeak \times Ahru)^{0.56} Kusle \times Cusle \times Pusle \times LSusle \times Cfrg \qquad (4)$$

Where, *Tsediment* is the sediment yield in metric tons, *Qsurf* is the surface runoff volume in millimeters per hectare, *qpeak* is the peak runoff rate in m^3/s, *Ahru* is the area of hydrologic response unit in hectares, *Kusle* is the soil erodibility factor, *Cusle* is the cover and management factor, *Pusle* is the support practice factor, *LSusle* is the topographic factor, and *Cfrg* is the coarse fragment factor. The description of the SWAT model and its different components is explained in the documentation provided by Neitsch et al (2011).

2.2 Study Area

Lolab watershed presented in Figure 1 is one of the watersheds in Pohru catchment with an area estimated to be 45 km^2 and classified in three different physiographic units which are flood plains, karewas, and mountains (Ahmed and Mir., 2014). It lies between 34 °41’ to 34 °24’ N Latitude and 74 ° 09’ to 74 ° 23’ E Longitude with the elevation starting from 1500 meters and reaching up to 3900 meters. The study area is mostly dominated by cambrio-slurian formations and panjal traps followed by Agglomeratic slates, granites and recent alluvium (Thakur and Rawat, 1992) with the most of the land used for agriculture as observed with 34.14 % of the total watershed area it covers followed by the sparse forest cover with 26.18 %. The major class of soil in Lolab is Fine Loamy which accounts for 79.58% of the total watershed area and, being a mountainous area, it majorly varies from steep to very steep with the slope found to be more than 9 degrees.

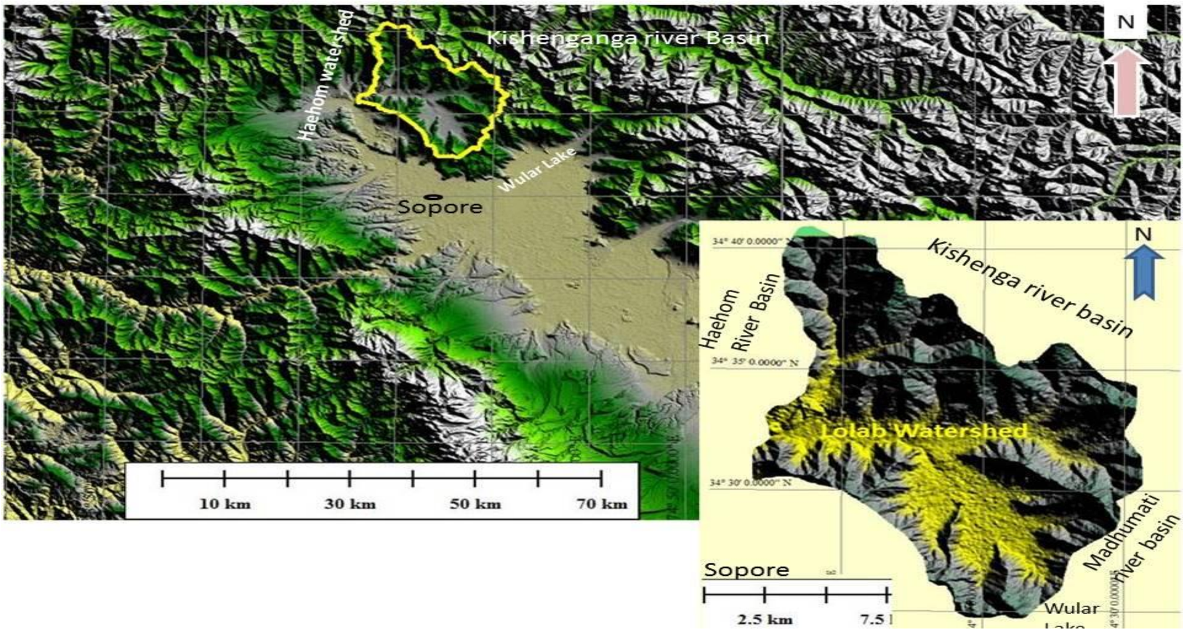

Figure 1. Study Area (Lolab Watershed of Pohru Catchment)

2.3 Data Requirement and Preparation

Different inputs were used by SWAT at watershed, sub-basin, and HRU (Hydrologic Response Unit) levels (Arnold et al., 2012). The watershed level input was used to model the evapotranspiration applied in analyzing all the HRU's in the watershed, sub-basin level inputs such as precipitation and temperature data were implemented to simulate all the HRU in a particular sub-basin while the HRU level inputs were set to unique values for individual HRU such as management scenarios. Moreover, ArcSWAT 2012 required a spatial database digital elevation model (DEM), land use/land cover, and soil characteristics while meteorological data used include daily rainfall, temperature, relative humidity, solar radiation, wind speed, etc. Hydrological data were also observed to conduct sensitivity analysis.

2.4 Model Setup

SWAT model (2012 version) was integrated with ArcGIS (version 10.1) to ensure the effective use of spatial data in enhancing model behavior and providing a user-friendly editing environment. Watershed was automatically delineated into sub-basins and further into Hydrologic Response Units (HRUs) to describe spatial heterogeneity in terms of slope, land cover, and soil characteristics within the catchment. The first step was to import a 30 m × 30 m resolution Digital Elevation Map after which a polyline stream network data set was burnt into SWAT to improve the hydrological segmentation and reduce the processing time. The different inputs used by the model and their source are listed in Table 1. Moreover, a threshold critical source area of 300 hectares was used and delineated into 43 sub-basins while a land use/ land use cover map with 100 m × 100 m resolution in a projected grid format was loaded into the SWAT along with the soil data to determine the spatial heterogeneity within each sub-basin to delineate the 43 sub-basins into 182 Hydrologic Response Units by considering 5%, 10%, and 10% threshold levels for land use, soil, and slope classes respectively. The land use classifications were also re-classified to match the classes recognized by SWAT as shown in Table 2.

Table 1. Sources of different inputs used in this study.

S/No	Input	Source	Resolution	Use
1	DEM	Derived from 30-meter STRM Data set	30 m × 30 m	a) Delineation of watershed b) Analysis of drainage pattern c) Derivation of slope
2	Land use / Land cover	Department of Geography, University of Kashmir	100 m × 100 m	a) Categorization of area b) Affects Runoff, evapotranspiration and other hydrological processes
3	Soil data	Soil conservation Department, Kashmir	250 m × 250 m 3 soil profiles	a) Categorization for individual HRU's
4	Weather data	Meteorological Department of Kashmir	4 gauging stations	Model inputs for evaluation of hydrological data
5	Measured data for runoff and sediment yield	Irrigation and Flood Control Department Kashmir	Daily data from Jan 2009 - Dec 2017	Data used for calibration and validation of estimated data

Table 2. Re-classification of Land-use/ Land cover classes

S/ No	Land use Class	Re-classification into 4-letter SWAT code	Percentage area
1	Dense forests	FRSD	9.18
2	Moderate forests	FRSD	8.98
3	Sparse forests	FRSD	26.18
4	Agriculture	AGRL	34.14
5	Horticulture	RNGE	10.39
6	Water bodies	WATR	7.52
7	Snow	WATR	3.61

SWAT description used in reclassifying land use/land cover map was obtained from USDA-NASS (The United States Department of Agriculture-National Agricultural Statistics Science cropland data layer).

2.5 Model Calibration and Validation

SWAT model was applied to the watershed understudy for 8 years from 2010-2017 with those from 2010-2013 used for calibration while 2014-2017 was used for validation. The SWAT has manual calibration as well as auto-calibration built-ins, but the manual calibration was avoided in this study because it is a time-consuming procedure (Eckhardt & Arnold, 2001) and its successes depend on the experience of the modeler. The Auto-calibration technique was, however, implemented to calibrate and determine the optimal parameters using the Shuffled Complex Evolution Method (SCEM) algorithms (Arnold et al., 2012). Moreover, after the most sensitive parameters for both stream-flow and sediment yield have been determined, the model was validated and its efficiency evaluated using Coefficient of determination (R^2) and Nash-Sutcliffe Coefficient (N_{SE}) provided in Equations (5) and (6) respectively (Tuppad et al., 2011).

$$N_{SE} = 1 - \frac{\sum_{i=1}^{n}(Observed_i - Predicted_i)^2}{\sum_{i=1}^{n}(Observed_i - Mean_{Observed})^2} \qquad (5)$$

$$R^2 = \left\{\frac{\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{Observed_i} - \mathrm{Observed_{mean}})(\mathrm{Predicted_i} - \mathrm{Predicted_{mean}}]}{[\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{Observed_i} - \mathrm{Observed_{mean}})^2]^{1/2}[\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{Predicted_i} - \mathrm{Predicted_{mean}})^2]^{1/2}}\right\}^2 \qquad (6)$$

Where, N_{SE} is Nash-Sutcliffe coefficient, R^2 is coefficient of determination,$Observed_i$ is the actual data measured for the period i,$Predicted_i$ is the data estimated by the model for the period i,$Mean_{Observed}$ is the mean of the actual data measured,$Predicted_{mean}$ is the mean of data estimated by the model, and n is the number of values compared.

Nash-Sutcliffe provides the efficiency between -∞ to 1 in order to relate the goodness-of-fit of the model with the variance of observed data. An efficiency of 1 indicates a perfect match between the data estimated by the model and those actually observed, zero means the data estimated is as accurate as the mean of those observed, a value less than zero depicts inefficiency of the model while the values between 0.7 to 1 show the model predicts extremely well (Calder, I.R., 1998).

The coefficient of determination value lies between zero and 1 with the zero indicating lack of correlation between the actual measured data and those predicted by the model while 1 indicates a perfect match between the two sets of data.

3 RESULTS AND DISCUSSION

The first simulation by SWAT was unable to quantify the desired outcome with the actual peak discharges underestimated and the model calibration was considered necessary. The four most sensitive parameters were identified and calibrated accordingly to improve the efficiency of the model and later modified according to the procedure and ranges defined in the documentation (Arnold et al., 2012). Moreover, the initial soil conservation service Curve Number II was increased from the original value by 16% to amplify the runoff through a reduction in the total infiltration. The available soil water capacity was also reduced by 10% to increase the movement of water through soil layers while the average slope length was moderated for each sub-basin with the values ranging from 46m-290m throughout the 43 sub-basins. Furthermore, the saturated hydraulic conductivity was decreased by 8% to reduce the lateral flows. All these sensitive parameters used in estimating runoff are summarized in Table 3 with their ranks.The two most sensitive parameters identified to calibrate the sediment include channel erodibility and cover factors with values adjusted to 0.65 and 0.43 respectively as summarized in the following Table 4.

The monthly observed values and those predicted by the model for runoffs in the calibration period 2010-2013 were in an average relationship with each other as indicated by the Nash-Sutcliffe efficiency and Coefficient of determination which was 0.56 and 0.81 respectively as shown in Figure 2 and observed to have increased to 0.98 and 0.99 for the validation period 2013-2017 as presented in Figure 3. The efficiency of SWAT with the fitting equation between observed and simulated values for runoff during calibration and validation period is presented in Table 5.

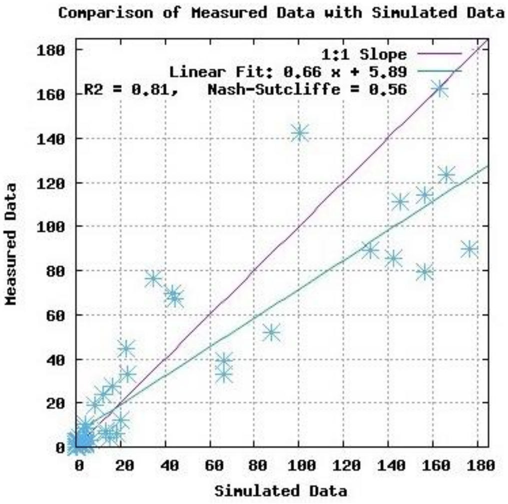

Figure 2. Scatter plot showing the relation between observed and predicted runoff (Calibration period)

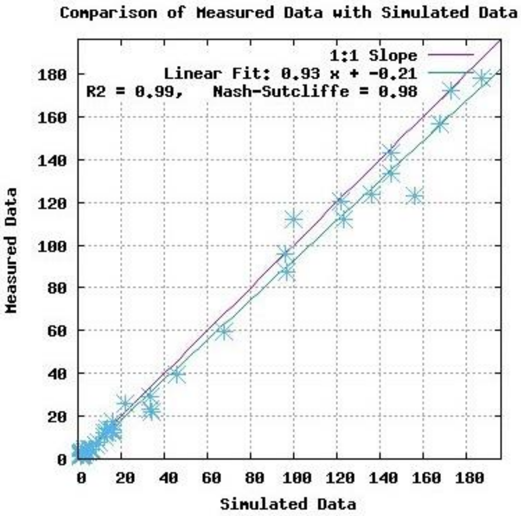

Figure 3. Scatter plot showing the relation between the observed and predicted runoff(Validation period).

Table 3. Most sensitive parameters for runoff estimation

Parameter	Rank	Range of calibration	Calibrated value
Initial Soil Conservation Service Curve Number II	1	±25%	16%
Available Soil Water Capacity	2	±25%	10%
Average Slope Length in meters	3	10 to 300	46-290
Saturated Hydraulic Conductivity (mm/h)	4	±15%	8%

Table 4. Most sensitive parameters for Sediment yield estimation

Parameter	Rank	Range of calibration	Calibrated value
Channel erodibility factor	1	0-1	0.65
Channel cover factor	2	0-1	0.43

Table 5. Efficiency of the SWAT model to predict runoff during calibration and validation period

Observed and Predicted Runoff(mm)	Nash-Sutcliffe Efficiency	Coefficient of determination	Linear fit equation (*Y*= predicted flow; *x*=observed flow)
Calibration Period (2010-2013)	0.56	0.81	$Y= 0.66x+5.89$
Validation Period (2013-2017)	0.98	0.99	$Y=0.93x-0.21$

The SWAT model showed satisfactory results during the process of modeling the sediment yield as observed with the Nash-Sutcliffe efficiency and Coefficient of determination recorded at 0.75 and 0.76 respectively during the calibration period as indicated in Figure 4. The values were observed to have increased to 0.91 and 0.94 during the validation period as shown in Figure 5. These values along with the fitting equations are presented in Table 6. Meanwhile, SWAT tended to underestimate the runoff during high-flow periods even though the statistical evaluation showed satisfactory runoff simulation for both calibration and validation periods. This is partly associated with the inability of the present curve number technique to generate accurate runoff prediction for a day with an experience of several storms. Meanwhile, soil moisture level and corresponding runoff curve number have been reported to be varying from one storm to another (Kim et al., 2018) while SCS-CN methods were used to define a rainfall event as the sum of all rainfall in one day and this has the ability to lead to underestimation of runoff (Chow et al., 1988).

The bar-charts showing the variation between the observed and predicted values of runoff during the calibration and validation periods are presented in Figure 6 and 7 respectively. A plot of monthly observed and predicted sediment yield during the calibration and validation periods are shown in the form of bar-charts in Figure 8 and 9 respectively

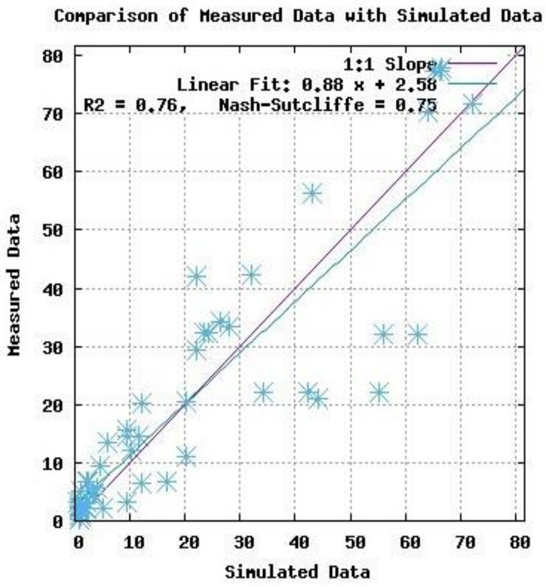

Figure 4. Scatter plot showing the relation between the observed and predicted sediment (Calibration period)

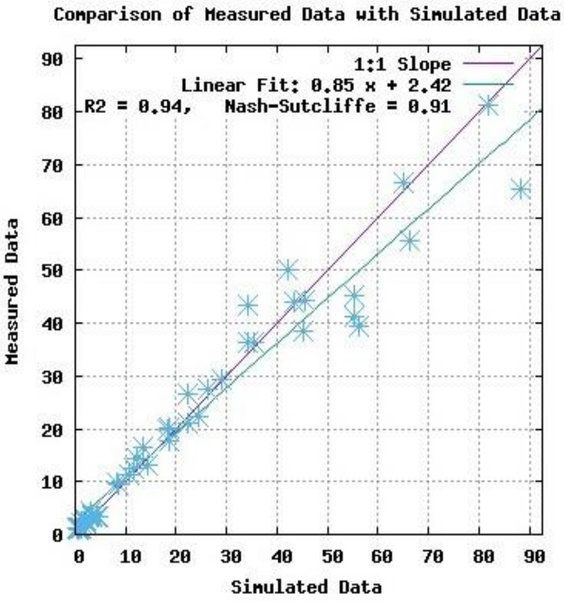

Figure 5. Scatter plot showing the relation between the observed and predicted sediment (validation period)

Table 6. Efficiency of the SWAT model to predict sediment yield during calibration and validation period.

Observed and Predicted Sediment yield (t/ha)	Nash-Sutcliffe Efficiency	Coefficient of determination	Linear fit equation (Y= predicted yield; x=observed yield)
Calibration Period (2010-2013)	0.75	0.76	$Y= 0.88x+2.58$
Validation Period (2013-2017)	0.91	0.94	$Y=0.85x+2.42$

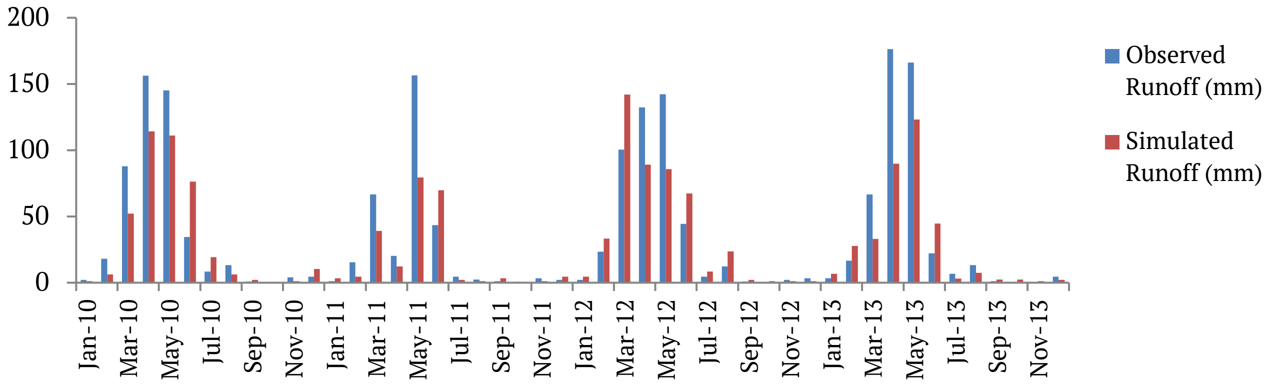

Figure 6. Bar-chart showing monthly values of observed and predicted runoff during the calibration period.

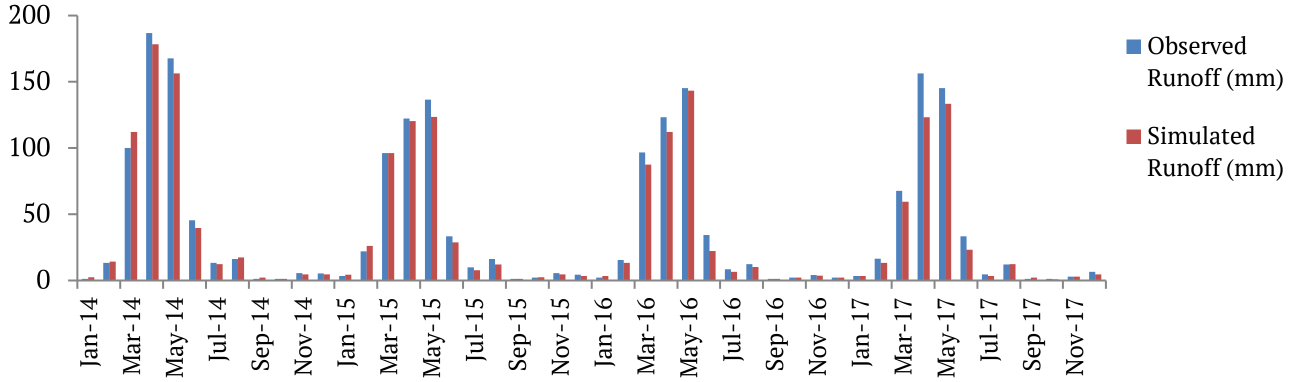

Figure 7. Bar-chart showing monthly values of observed and predicted runoff during the validation period.

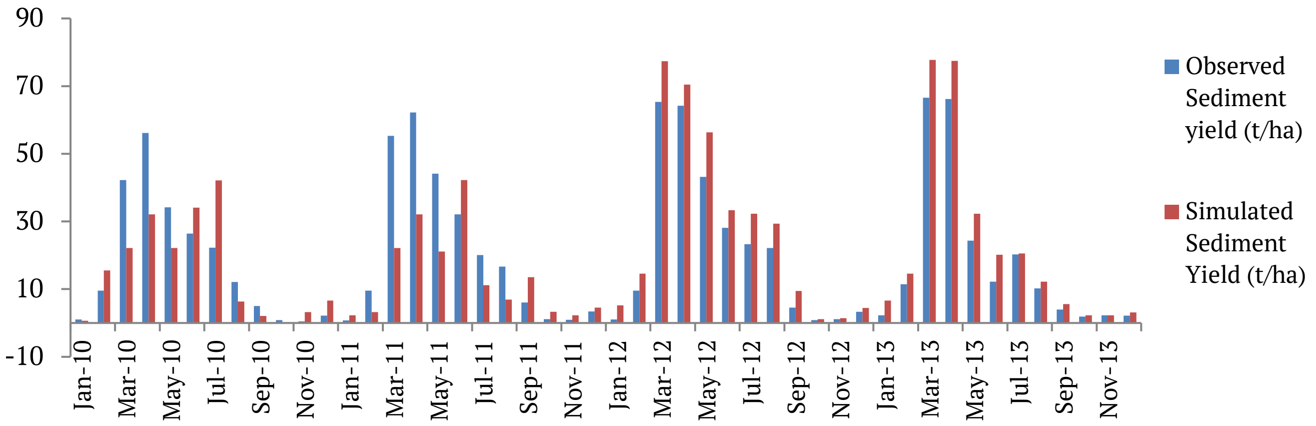

Figure 8. Bar-chart showing monthly values of observed and predicted sediment yield during the calibration period.

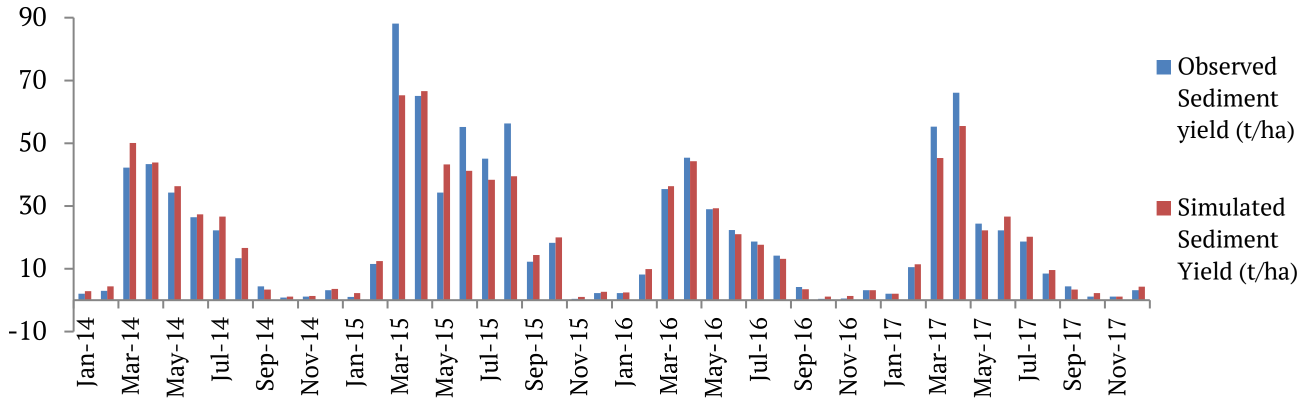

Figure 9. Bar-chart showing monthly values of observed and predicted sediment yield during the validation period.

The annual average sediment drawn from each sub-basin was calculated to determine the most problematic sub-basins which were used to prepare the prioritization map shown in Figure 10.

The sub-basins were categorized into very severe, severe, medium, and low severity areas as shown in Table 7, and approximately 40% of the total area of the watershed were classified as very severe to severe erosion zone. Moreover, the existing conditions of the sub-basins numbered 1, 4, 6, 7, 28, and 37 were found to be generating maximum annual average sediment yield. It is, however, possible to reduce this through several intervention strategies such as land slope stabilization, construction of bench terraces, changing the land use of the steep area, and afforestation

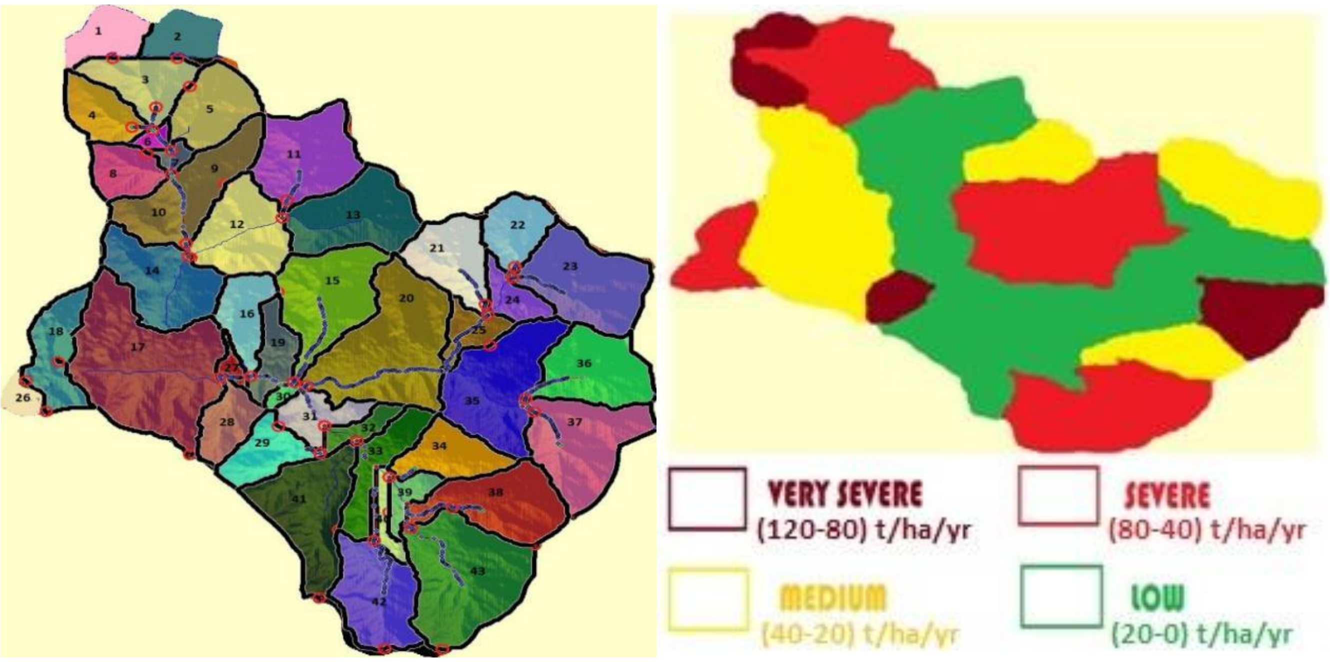

Figure 10. Watershed prioritization map shoving the severity level of erosion in different sub-basins

Table 7. Severity level of sub-basins of Lolab watershed

S/No	Severity level	Sub-basin numbers	Percentage area	Annual average sediment yield (t/ha/yr)
1	Very severe	1,4,6,7,28,37	10.47	80-120
2	severe	2,3,5,15,18,20,21,25,26,42,43	29.17	40-80
3	medium	8,10,13,14,17,22,23,38,39	24.22	20-40
4	low	9,11,12,16,19,24,27,29,30,31,32,33,34,35,36,39,40,41	36.14	0-20

4 CONCLUSION

It is necessary to understand the hydrological parameters at sub-basin or even smaller levels in order to determine the most problematic areas and factors responsible for the degradation of the whole watershed even though several efforts have been made to address the soil erosion problem at the grass-root level and different conventional methods applied to determine hydrological behavior at the watershed level. This study made use of a semi-distributed physical model known as SWAT (Soil and Water Assessment Tool) to assess the hydrological behavior of a small watershed in Pohru catchment of Kashmir valley. The aim was to determine the efficiency of the model in predicting the runoff and sediment yield of Lolab watershed and identify the most problematic sub-basins drawing the maximum amount of sediment.

The values estimated by the model were compared with the actual data and they were both observed to be in good agreement as indicated by Nash-Sutcliffe efficiencies found to be 0.56 and 0.75 for runoff and sediment yield as well as the coefficient of determination at 0.81 and 0.76 respectively during the calibration period. These values were discovered to increase to 0.98 and 0.91 for Nash-Sutcliffe and 0.99 and 0.94 for the coefficient of determination for runoff and sediment yield respectively during the validation period.

A prioritization map was prepared to determine the areas drawing the maximum amount of sediment in order to apply the appropriate intervention strategies to manage the watershed. The SWAT was also generally found to be a good analyzing tool to assess the hydrological behavior of highly gullied regions and other un-gauged basins of Kashmir valley.

DISCLAIMER

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

Authors are thankful to the Department of Soil Water Conservation, Government of Jammu and Kashmir, India for providing data of runoff and sediment yield of the study area. The authors are grateful for the critical comments of anonymous reviewers and the Editor, which helped in improving the quality of this paper.

REFERENCES

Ahmed, P., & Mir, A. A., 2014. Sediment Yield Estimation for Watershed Management in Lolab Watershed of Jammu & Kashmir State using Geospatial Tools. *International Journal of Advanced Remote Sensing and GIS*, 3,pp. 616-626.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., & Kannan, N., 2012. SWAT: Model Use, Calibration, and Validation.*Transactions of the ASABE*,55(4), pp.1491-1508.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R., 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development 1. *JAWRA Journal of the American Water Resources Association*, 34(1), pp. 73-89.

Bisantino, T., Bingner, R., Chouaib, W., Gentile, F., & Trisorio L. G., 2015. Estimation of Runoff, Peak Discharge and Sediment Load at The Event Scale in a Medium-Size Mediterranean Watershed Using The AnnAGNPS model. *Land Degradation & Development*, 26(4), pp. 340-355.

Calder, I. R., 1998. Water-Resource and Land-Use Issues. *Swim Paper* 3.

Chow, V.T., Maidment, D.R., & Mays, L.W., 1988. *Applied Hydrology*. New York: McGraw-Hill.

Eckhardt, K., & Arnold, J. G., 2001. Automatic Calibration of a Distributed Catchment Model. *Journal of Hydrology*, 251(1-2), pp. 103-109.

Gull, S., & Shah, S. R., 2020. Watershed Models for Assessment of Hydrological Behavior of The Catchments: A Comparative Study. *Water Practice and Technology*, 15 (2), pp. 261-281.

Gull, S., Ahangar, M. A., & Dar, A. M., 2017. Prediction of Stream Flow and Sediment Yield of Lolab Watershed Using Swat Model. *HydrolCurr. Res*, *8*, pp. 265.

Himanshu, S. K., Pandey, A., & Shrestha, P., 2017. Application of SWAT in an Indian River Basin for Modeling Runoff, Sediment and Water Balance. *Environmental Earth Sciences*, 76(1), pp. 3.

Kim, J., Johnson, L. E., Cifelli, R., Choi, J., & Chandrasekar, V., 2018. Derivation of Soil Moisture Recovery Relation using Soil Conservation Service (SCS) Curve Number Method. *Water*, 10(7), pp. 833.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R., 2011. *Soil and Water Assessment Tool Theoretical Documentation Version 2009*. Texas: Texas Water Resources Institute.

Nikolaidis, N. P., Bouraoui, F., & Bidoglio, G., 2013. Hydrologic and Geochemical Modeling of a Karstic Mediterranean Watershed. *Journal of Hydrology*, 477, pp. 129-138.

Pradhan, P., Tingsanchali, T., & Shrestha, S., 2020. Evaluation of Soil and Water Assessment Tool and Artificial Neural Network Models for Hydrologic Simulation in Different Climatic Regions of Asia. *Science of the Total Environment*, 701, pp. 134308.

SCS, U., 1985. *National Engineering Handbook*, section 4: Hydrology. Washington DC: US Soil Conservation Service, USDA.

Setegn, S. G., Srinivasan, R., & Dargahi, B., 2008. Hydrological Modelling in the Lake Tana Basin, Ethiopia using SWAT Model. *The Open Hydrology Journal*, 2(1).

Shen, Z. Y., Gong, Y. W., Li, Y. H., Hong, Q., Xu, L., & Liu, R. M., 2009. A Comparison of WEPP and SWAT for Modeling Soil Erosion of the Zhangjiachong Watershed in the Three Gorges Reservoir Area. *Agricultural Water Management*, 96(10), pp. 1435-1442.

Sorooshian, S., 1991. Parameter estimation, model identification, and model validation: conceptual-type models. *In Recent Advances in the Modeling of Hydrologic Systems* (pp. 443-467). Dordrecht: Springer.

Thakur, V. C., & Rawat, B. S., 1992. Geological Map of the Western Himalaya. Scale 1: 1,111,111.

Tuppad, P., Mankin, D., K. R., Lee, T., Srinivasan, R., & Arnold, J. G., 2011. Soil and Water Assessment Tool (SWAT) Hydrologic/Water Quality Model: Extended Capability and Wider Adoption. *Transactions of the ASABE*, 54(5), pp. 1677-1684.

Van Andel, T., 2010. African Rice (*Oryza glaberrima Steud.*): Lost Crop of the Enslaved Africans Discovered in Suriname. *Economic botany*, 64(1), pp. 1-10.

Wheater, H. *S.*, Jakeman, A. J., & Beven, K. J., 1993. Progress and directions in rainfall-runoff modeling. In: Jakeman, A.K., Beck, M.B., McAleer, M.J. (Eds.), Modeling change in environmental systems. *John Wiley* & *Sons*, *Chichester*, UK, *pp. 101–132*.

Wischmeier, W. H., & Smith, D. D., 1978. Predicting rainfall erosion losses-a guide to conservation planning. Predicting rainfall erosion losses-a guide to conservation planning.

Zhang, S., Liu, Y., & Wang, T., 2014. How Land Use Change Contributes to Reducing Soil Erosion in the Jialing River Basin, China. *Agricultural Water Management*, 133, pp. 65-73

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