International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958 (Online), Volume-9 Issue-5, June 2020

Hydrological Modelling of Sediment Yield of Agr0 -Forestry Watershed

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Abstract**:** ***For this analysis, the Manot sub-basin region of Upper Narmada Basin located in Madhya Pradesh, India, is designated for estimation of runoff, sediment load, sediment concentration and sediment yield using SWAT. The model was implemented during 1989 and 2008. NBSSLUP soil data, Digital Elevation Model (DEM), slope, Land use Ground cover (LULC) and climate records of temperature and rainfall were used as inputs for the Manot Gauge Station. The forecasted model discharge was estimated statistically and compared the real daily flow data from 1989 to 2008, which corresponds to a major number. The R2 value (coefficient of determination) for discharge, sediment concentration, sediment load and sediment yield values for the period 1989 to 2008 were found to be 0.95, 0.94, 0.96 and 0.96 respectively. RMSE for discharge, sediment concentration and sediment yield were found to be 0.32, 0.27 and 0.17, respectively. The expected sediment load at the Manot Gauge Station for the duration (1989–2008) is 6670918 tons per year and the observed sediment load is 6255565 tons per year. Simulated sediment load and measured sediment load at the Manot Gauge Station are 14.13 tons / year / hectare and 15.02 tons / year / hectare, respectively. Predicted sediment concentrations and measured sediment concentrations at the Manot gauging station were found to be 8.81 ppm and 7.46 ppm, respectively. Similarly, the expected and observed Sediment Yield was 1.513 mm and 1.704 mm respectively.***

Keywords: SWAT, Hydrological modeling, Sediment Concentration, Sediment Yield.

I. INTRODUCTION

The natural ecosystem consists of the topsoil, stream and plant surroundings required for the continued survival and comfort of humankind (1). In the past, the Earth system has been troubled by over-exploration of the ecosystem at the peak of requirements due to industrial growth, etc. Deforestation resulting in bare soil surface results in soil erosion (2). The soil that has been eroded is deposited in the reservoir, thereby reducing its ability. Increased soil erosion, which is caused by human activity, is correlated with soil productivity by eliminating the active topsoil and reducing the lifetime of the storage reservoir by sediment particles (3). Sediment yield simulation concerned concentration but a lack of sources and a valid method for estimating it are some of the obstacles in this trend (4). Collection of sediment discharge data during the year and regular basin investigation data (5) are key challenges in predicting sediment yield rates at the basin level (6). SWAT was effectively used by scientists for distributed hydrologic simulation and managing waterbodies in the catchment. (7) across variety of environment and topography parameters. It shows that SWAT can provide sufficient hydrologic simulation associated with weather change in basins. (8). One of the key difficulties of the dam technique is the accumulation of sediment in its reservoir, which results in a decrease in its storage capacity (9). This affects the different structural components of the dam (10). The storage potential of dams is of considerable significance in regions where water shortages exist (11). Topsoil particles removed from a basin could not be transported up to opening of basin due to their trapping in the upstream areas (12). Research has shown that storage reservoirs reduce their capacity effectively by deposition of sediment particles to 1–2 % annually (13). Sedimentation continues to be one of the biggest concerns of the river environment. Sediment is a contaminant that impairs most of the streams in the soil erosion model (14) that defined the deposition, settlement and movement of soil elements by precipitation and discharged water from its point of source to the watershed outlet (15). Sediment yield amount is an integrated measure of destruction, conveyance, and settling processes (16). The sediment system in the basin is not solitary sediment yield (17) but also counting sediment movement with the rivers (18).

Water associated action that occurs in one part of a stream catchment may have an effect on the other part (19). Analysis of sedimentation is needed for the study of the storage capacity of the reservoir (20). This involves the collection of water samples from measuring stations on a regular basis (21). Sediment gauging networks provide the vital data needed to create a precise sediment budget defined for four major sediment exchanges for a large, physically efficient river (22).

In this analysis, the SWAT model is used to estimate the soil loss prediction of the Manot basin of Upper Narmada River.

Revised Manuscript Received on May 15, 2020.
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The area selected for this analysis (Fig.1) is part of the upper Narmada basin from the sources of the Narmada River (Amarkantak) to the Manot Gauge Site situated on the main Narmada River in central India and the fifth longest river in India. Manot is situated at 80° 31' longitude and 22° 44' latitude at 475 m above Sea Level with a total surface area of 4467 sq. km.

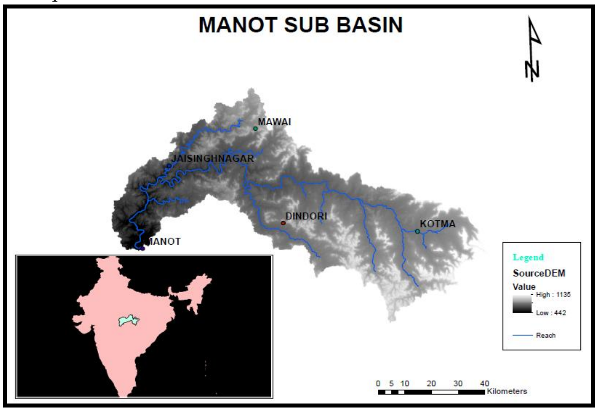

Figure 1 Manot Sub Basin of Upper Narmada River basin

The specifics of the Manot gauge stations are shown in Table 1 which is located at 22o 44 'and 80o 30' latitude and longitude.

Table 1Details of Manot Gauge station

STATION NAME	RIVER/ TRIBUTARY	TYPE	LENGTH OF RIVER (KM.)	DRAINAGE AREA (SQ. KM.)
Manot	Narmada river	GDSQ	265	4667

The specifics of the Manot gauge stations are shown in Table 1 which is located at 22o 44 'and 80o 30' latitude and longitude.

Table 2 Details of Rain gauge station of Manot Basin

STATION NAME	LATITUDE	LONGITUDE	TYPES OF STATION
Manot	22^0 44' 09"	80^0 30' 44"	GDSQ
Jaysingnagar	22^0 37' 06"	80^0 34' 45"	Rain Gauge
Mawai	22^0 30' 00"	81^0 04' 15"	Rain Gauge
Dindori	22° 56' 52"	81° 04' 34"	Rain Gauge
Kotma	23° 12' 00"	82° 01' 00"	Rain Gauge

II. DATA COLLECTION

The data required for catchment hydrology modeling are hydro-meteorological, geomorphological, agricultural, geological and hydrological. The SWAT model requires different input types, such as soil classification, LULC, topography, atmosphere, etc. Input data were obtained from various sources, such as soil data from NBSSULP, LULC images from L8OLI / TIRS, climate data like precipitation, temperature data were obtained from CWC, IMD, and NCA.

The total number of observation sites in the area is shown in Figure 2. Manot is the lower boundary of the Upper Narmada Basin. The annual / seasonal sediment yield in mm is the average soil height in mm of the reservoir equal to the annual suspended sediment runoff measured at the gauging station. It is computed using the relation. (Hydrological Data Book, CWC 2009) given in equation 1.

$$\text{Total Sediment Yield} = \frac{\text{Total Suspended Sediment Load x 1400}}{\text{Total Catchment Area } (Km)^2} \quad \text{--(1)}$$

III. DATA ANALYSIS

A. Precipitation

Data were collected from various sources have many missing data such as daily data or station data for a particular period which can be interpolated from various tools. Precipitation has many missing values that were taken into account and the percentage of missing data was find out using the Thiessen Polygon method and comparison method. The comparison method (equation number 2) was used when the yearly precipitation at any station changes from the interpolation station by greater than 10 %

$$Pm = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Nm}{Ni}\right)Pi \quad \text{---------------(2)}$$

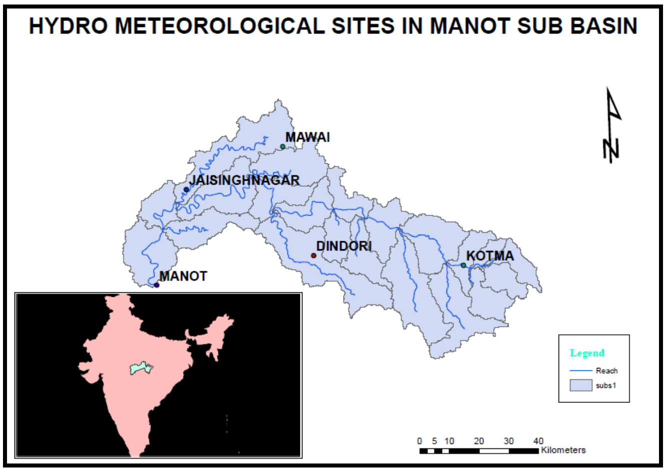

Figure 2 Hydro meteorological sites in Manot Sub Basin

B. Discharge

Missing data of discharge was found by using the interpolation method using the best-fit curve method from available rainfall data.

C. Bad data rejection

The bad data was removed using Chauvenet's criteria. in which the expected number of records at least as bad as the expected record less than 1/2, then the expected measurement should be rejected. According to this, each value has a 50% chance of continued existence. (Figure 3)

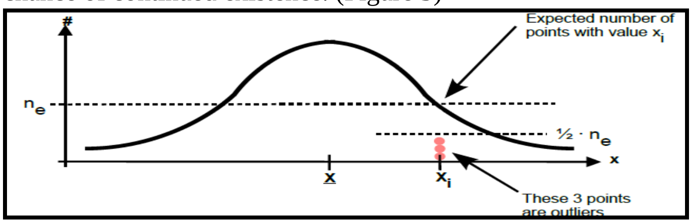

Figure 3 Chauvenet's Criteria for Bad Data Rejection

D. *SWAT Input Layers*

SWAT model needs various input records such s soil, climate, land use, topography, etc. Data were composed of many sources as described below and various procedures have been carried out.

ISSN: 2249 – 8958 (Online), Volume-9 Issue-5, June 2020

E. Digital Elevation Model (DEM)

DEM was obtained from the SRTM (Shuttle Radar Topography Mission) with a resolution of 30x 30 m. This means that every pixel of the DEM has a surface area of 900 m2. Figure 4 shows the DEM for the area.

F. Land Use Land Cover

The images from satellite IRS L8OLI/TIRS (resolution 30 m) was geo-referenced with related toposheets of SRTM. Supervised classification was done using the maximum likelihood algorithm. The SWAT view of the LULC map for the Manot sub-basin of the upper Narmada Basin is shown in Figure 4. The main region of the catchment covered in forest and grassland areas. The proportion covered in the Manot sub-basin forest (45.73%), agriculture and grassland (36.50%), urban residential (9.26%), and water (8.50%).

G. Soil Classification

The soil map and its belongings for the basin were collected from the NBSSLUP, digitized and graded into different soil groups and used in the analysis. Soils were categorized into four major groups, such as group A, group B, group C, and group D, on the basis of their infiltration capability. (Figure 4)

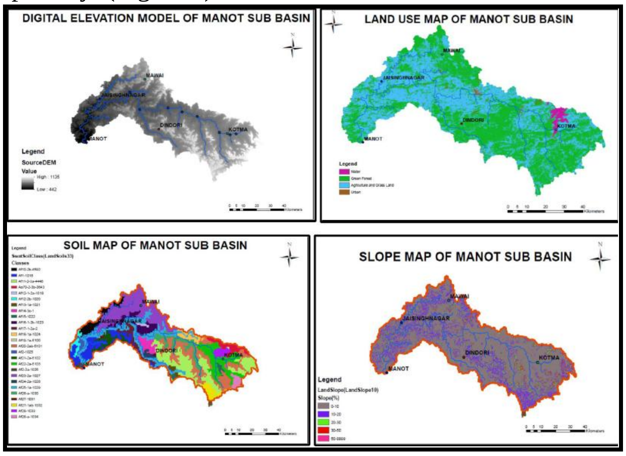

Figure 4 Digital Input Layers of Manot Basin

H. Slope Map

Longer slope accumulates discharge from a huge region and also results in high flow velocity resulting in increased erosion in a non-linear manner. Steeper slopes produce higher overland flow velocity. Slope map of the Manot basin of the Upper Narmada sub-basin is shown in Figure 4.

I. Hydrological Response Unit (HRU)

In the SWAT model, a catchment is distributed into several basins based on slope class, soil type and land-use. Here SWAT divided the basin into 21 sub-basins each of them is the HRUs of the Manot basin which is shown in Figure 5.

IV. MATHODOLOGY

The SWAT is a distributed model, planned for estimation of impact of basin managing practice in a basin. SWAT pretends the complete hydrologic cycle of a basin. The SWAT model follow MUSLE to evaluate soil loss at the HRU level. The methodology used by SWAT is shown in Figure 6.

$$Qs = 11.8 (Y_{qpeak}: A)0:56.K.C.P.LS.CF \qquad \text{-----------(2)}$$

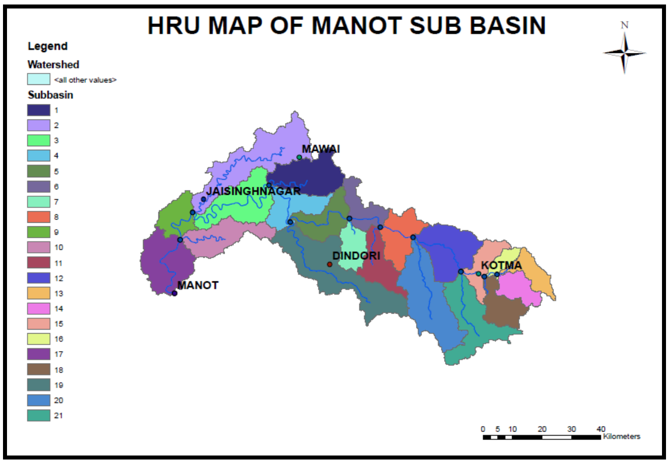

Figure 5 HRU model of Manot Basin

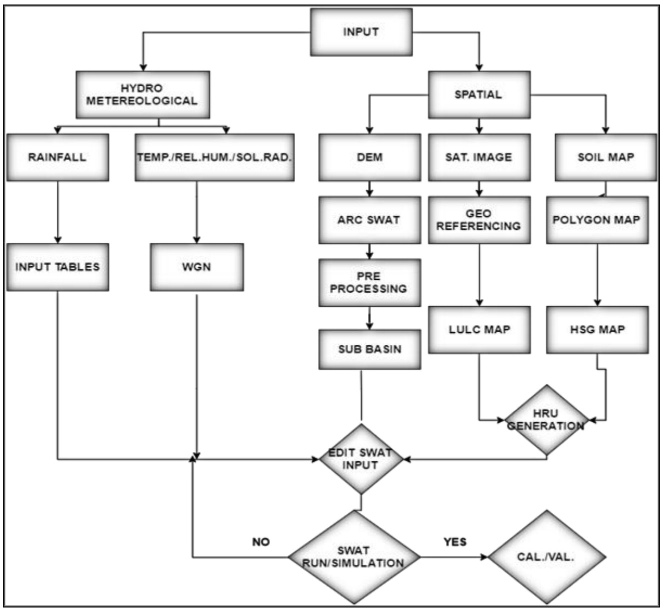

Figure 6 Flow Process of SWAT

Table 3 Criteria for SWAT

Criteria	Default Value	Calibrated Value	Faceable Range
Groundwater Delay (Days)	31	80	0-500
Alpha BF (Days)	0.048	0.15	0-1
GW REVA	0.02	0.2	0.02-0.2
RCHRG-DP	0.05	0	0-1
OV-N	0.1	0.013	0.01-30
ESCO	0	0.5	0-1
CURVE NUMBER	67	47	35-98
SOL-BD	1.61	0.9	0.9-2.5
SOL-AWC	0.15	0.4	0-1
SOL-K	43.15	20	0-2000

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DOI: 10.35940/ijeat.D9053.069520
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V. RESULT AND DISCUSSION

A. Rainfall-runoff for Manot Basin

SWAT model has been run for 20 years (January, 1989 to December 2008) for the Manot Basin of Upper Narmada River. A skewed normal method option was selected and result was created on a daily scale. Discharge and groundwater flow were summed at the outlet to estimate river flow. The rainfall-runoff curve has been developed and the relation between rainfall and runoff was found to be Q = 37.92P – 99.441 where Q = Runoff in m3/s and P = rainfall in mm and coefficient of determination is 0.91 as shown in Figure 7.

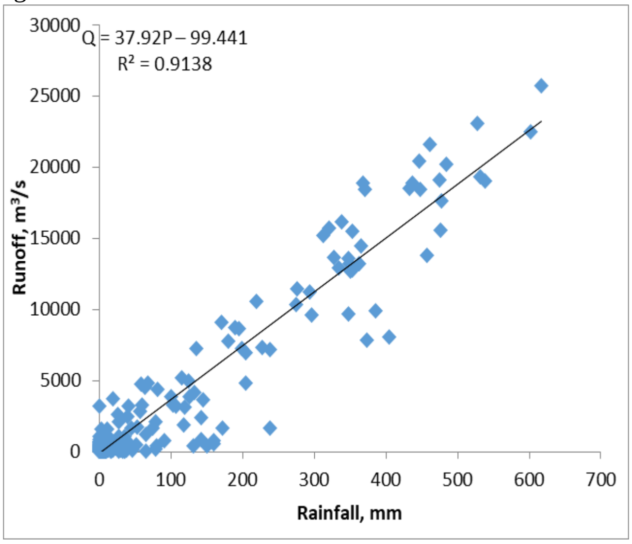

Figure 7 Rainfall-Runoff model for Manot basin.

B. Discharge analysis for Manot basin

Process parameters (as shown in Table 3) were adjusted with actual streamflow and weather record. To compare the model, predicted and observed runoff hydrographs at the Manot station were compared for twenty years, Figure 8 shows that the predicted hydrographs match with the actual discharge record. Figure 9 shows that the SWAT model simulates well of hydrology for the Manot basin of the upper Narmada river and the coefficient of determination was found to be 0.95.

C. Sediment Concentration for Manot basin

The model was first rectified for discharge and consequently for the sediment concentration. Figure 10 shows a graphical representation of discharge V/S suspended sediment concentration (Sediment rating curve) in power form and the coefficient of determination was found to be 0.901 and the relation between discharge and sediment concentration is Qs=0.013Q1.272

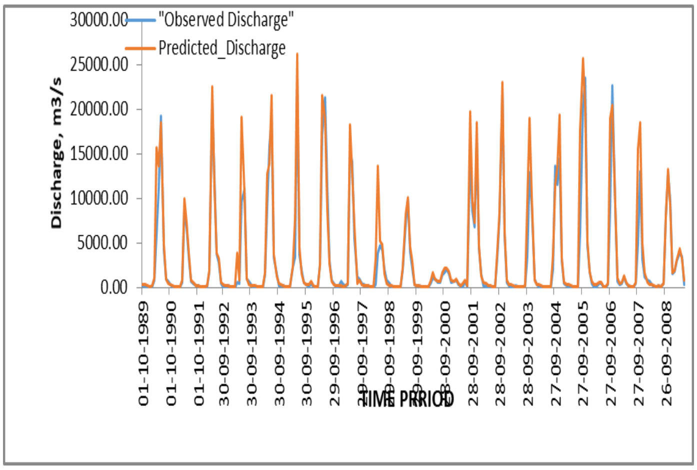

Figure 8 Variation in discharge

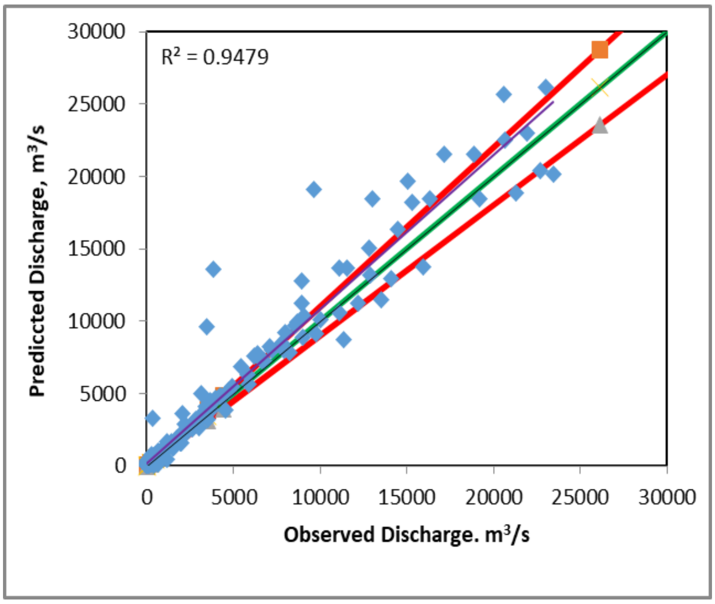

Figure 9 Percentage error is observed and predicted discharge

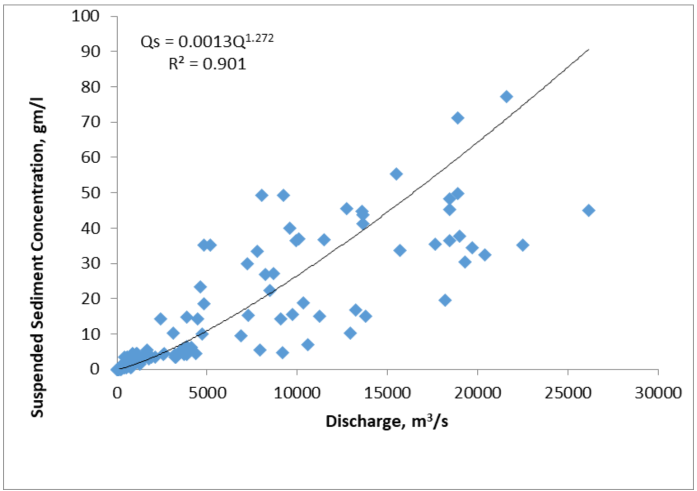

Figure 10 Sediment rating curve

Figure 11 shows the graphical representation of the variation in actual and estimated sediment concentration in gm/l. Figure 12 shows the percentage error of actual and estimated suspended sediment concentration and the coefficient of determination was found to be 0.94 which is acceptable.

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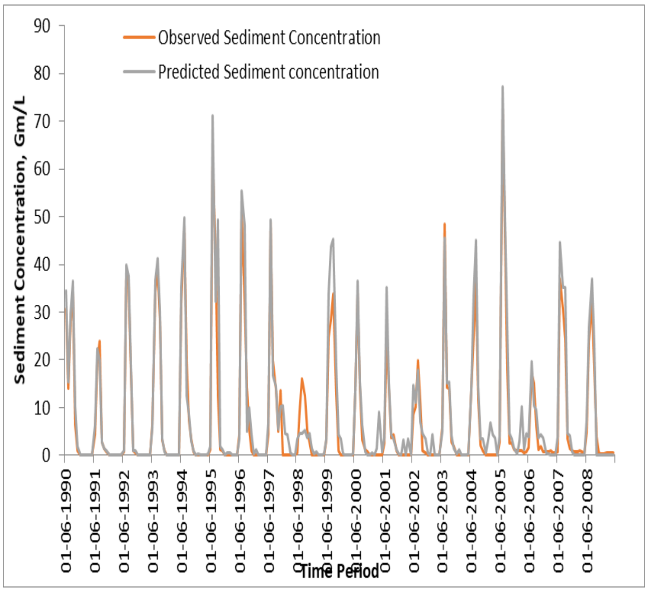

Figure 11 Variation in Observed and Predicted Sediment Concentration

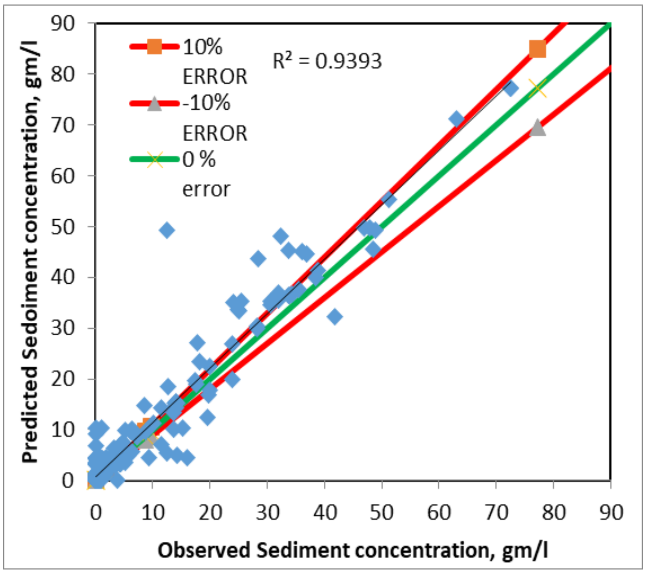

Figure 12 Percentage error in observed and predicted Sediment Concentration, gm/l

D. Sediment Load analysis for Manot basin

The model was rectified for discharge, sediment concentration, and consequently for sediment load and sediment yield. Figure 13 shows a graphical representation of the variation of observed and predicted sediment load in tons. Figure 14 shows the percentage error in observed and predicted sediment load and the coefficient of determination was found to be 0.96.

E. Sediment Yield analysis for Manot basin

Figure 15 represents the variation in observed and predicted sediment yield. The predicted sediment yield show differences with the actual record because the sediment particles may have deposited in the check dams etc. Average observed and predicted sediment yield was found to be 1.70 and 1.59 mm respectively. The percentage error or discrepancy ratio has been analysis and the coefficient of determination has been found out to be 0.955 as shown in Figure 16.

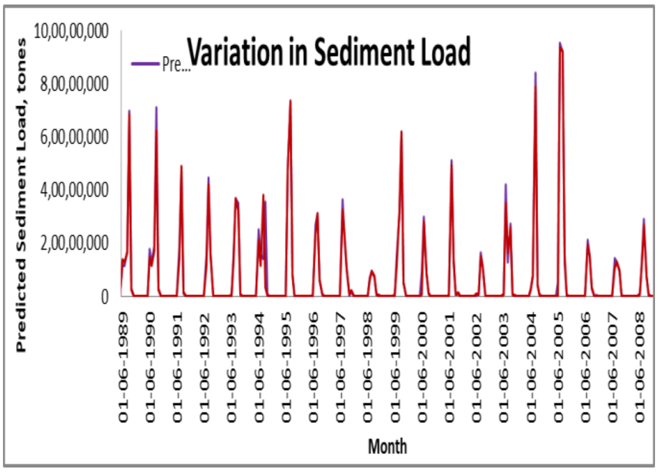

Figure 13 Variation in Sediment Load

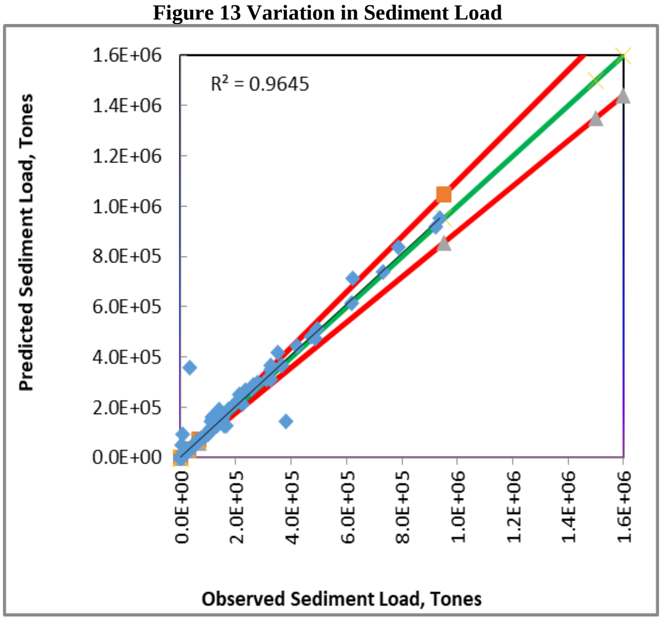

Figure 14 Percentage error is observed and predicted sediment load

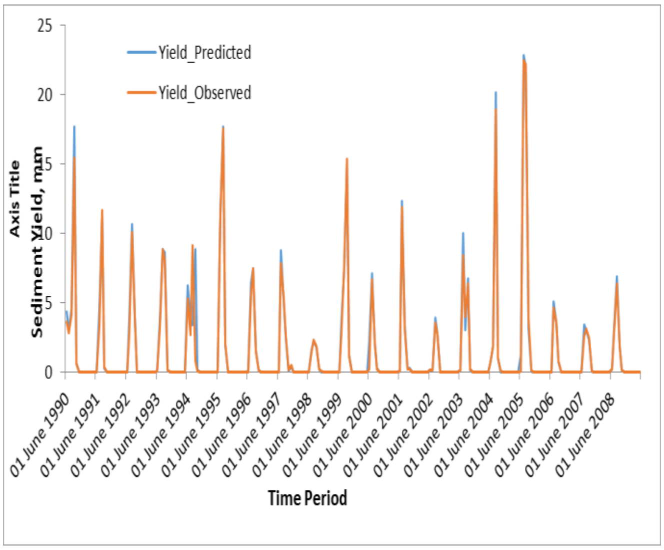

Figure 15 Variation in Sediment Yield

F. Root Mean Square Error (RMSE)

RMSE shows how much inaccuracy occurs between two records. In other words, it compares predicted and expected value.

A smaller value of RMSE indicated closer predicted and observed values are. Table 4 shows RMSE for discharge, sediment concentration, and sediment yield.

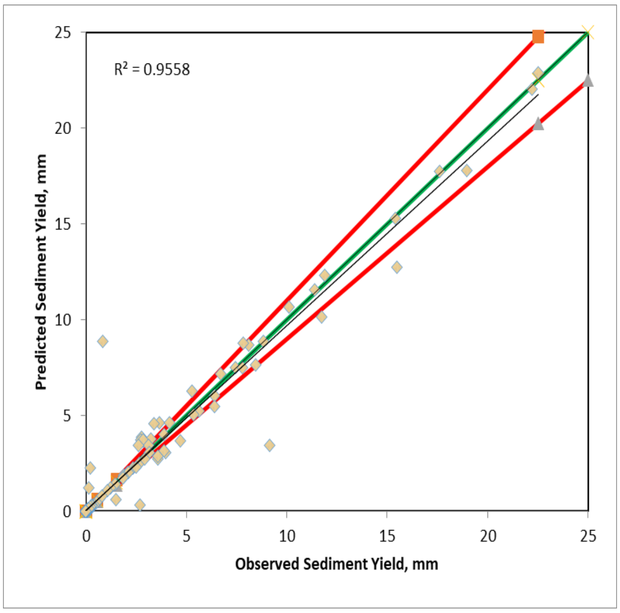

Figure 16 Percentage error in observed and predicted sediment yield.

$$RMSErrors = \sqrt{\frac{\sum_{i=1}^{n}(\bar{y}i-\bar{y})^2}{n}} \quad \text{-----------------(3)}$$

Table 4 RMSE for Discharge, Sediment concentration and sediment yield

RMSE	DISCHARGE	SEDIMENT CONCENTRATION	SEDIMENT YIELD
	0.33	0.17	0.27

G. *Cohen's kappa coefficient (κ)*

It is a study that matches the correlation between predicted and observed value. The kappa statistic (or kappa coefficient) is the most commonly used for this purpose[23]. Kappa coefficient can be determined by the equation given by Kappa.

$$K = (P0 - Pe)/(1 - Pe) \quad \text{-----------(4)}$$

Where P0 = Predicted value, Pe = Observed Value

Kappa of 1 states good relation, whereas a kappa of 0 specifies no relation. Table 5 shows the Kappa coefficient for runoff, sediment concentration, and sediment agreement for the observed and predicted results.

Table 5 Kappa Coefficient analysis

	Runoff	Sediment Concentration	Sediment Yield
Kappa Coefficient	0.87	0.78	0.70

VI. CONCLUSION

In this study, the SWAT model was simulated for the Manot basin, part of the Upper Narmada catchment for the reason to understand the rainfall-runoff process and rainfall-sedimentation process. From this study, the following findings can be evaluated. The SWAT model has simulated (period 1989–2008) for prediction of run-off and sediment yield at the reach of the Manot basin. The predicted sediment load at the Manot gauge station for the time-period (1989–2008) is 6670918 Tonnes per year and the observed sediment Load is 6255565 Tonnes per year. In terms of Tones/year/hectare predicted load 14.13 Tonnes/year/Hectare and observed load 15.02 tonnes/year/Hectare respectively. Predicted sediment concentration and predicted sediment concentration at Manot gauging station was found to be 8. 81 gm/l and 7.46 gm/l respectively. Similarly observed and predicted sediment yield was found to be 1.513 and 1.704 mm respectively.

The predicted discharge at the exit was compared with the observed discharge for twenty years (1989 to 2008) and the outcome is satisfactory. The coefficient of determination for the discharge was obtained as 0.95, 0.94 for sediment concentration, 0.96 for sediment load, and 0.96 for sediment yield can be considered as a satisfactory value.

Sediment rating curve was derived and the relation between discharge and sediment concentration was found to be Qs=0.013Q1.272 and the coefficient of determination between discharge and sediment load was found out to be 0.90.

RMSE for the discharge, sediment concentration, and sediment yield were found 0.32, 0.27, and 0.17 respectively. Kappa's coefficient for the discharge, sediment load, and sediment yield was found 0.87, 0.78, and 0.70 respectively. From, above analysis, it can be found that the SWAT model can be capable of simulation of the Upper Narmada river at the Manot basin.

It is found that in the following years, sediment yield decreases. Manot basin is a monitored catchment at an outlet of the basin but ungauged at sub-basin level, therefore a modeling approach to differentiate between the influence of land use and the dams is projected for further research. Various types of research are required to estimate the effects of hydraulic structures on basin hydrology and to predict responses of the basin. First, the local study that observes sediment deposition in the dams. Second, surveys of flow structure, sediment movement, and pattern of deposition in upstream and downstream of dams. The generated data from the surrey can be used to estimate theoretical models of flow over dams which act as walls to sediment movement.

ACKNOWLEDGMENT

The author highly acknowledges CWC (Central Water Commission, India), NCA (Narmada Control Authority) and IMD (Indian Meteorological Department) for providing data.

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