

# Physically Based Runoff and Sediment Modelling of Rawal Watershed

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**Abstract** - The sedimentation problem can be controlled if there is an idea regarding the amount of sediment being carried by the river flow from the catchment area by implementing effective watershed management strategies. This study was undertaken to analyze sediment yield from the Rawal Watershed. Simulation of flow and sediment yield from the watershed was conducted using SHETRAN model. The model was calibrated and verified for the local condition to determine the rate of erosion and sediment yield in the watershed. The available monthly flow data was used for model calibration. The simulated flow yielded good calibration results with a coefficient of efficiency (COE) of 0.98 and Percent Bias (PBIAS) coefficient of -2. The sediment data was generated from a relationship between discharge and sediment load. The calculated sediment data was used for the calibration and validation of the model. The sediment load calibration was done for the year 2001 with the coefficient of efficiency (COE) of 0.94 and Percent Bias (PBIAS) coefficient of -5.8 showing satisfactory model performances. The results obtained were quite accurate because of the fact that the sediment data was generated. The results can be made more meaningful if there is the availability of detailed (daily or hourly) flow and sediment data. The land use of a catchment was altered to analyze the impact of land use (vegetation) on the sediment yield. Based on the results, the SHETRAN model was confirmed to be a reliable tool for catchment sediment yield modeling including simulation of different land uses. Concrete efforts should be done to increase the forest area in the catchment so that sediment yield can be decreased.

certain point in a watershed (outlet) within a unit time is termed as sediment yield. Total erosion is always greater than sediment yield due to sediment deposition during transport. It is highly unpredictable because of the hydrological processes temporal variability, difficulty in measurement, and change of basin land management practices from year to year. The problem of high sediment concentration in rivers and sediment deposition in reservoirs produces clear effects on land and water resources. Water quality of the rivers and reservoirs has been deteriorated due to suspended sediment rate. The importance of reservoirs for water storage regarding irrigation, hydropower generation, flood control, drinking, and recreation purpose poses a lot of concern. It has become obligatory to consider sedimentation issues in the planning of water resource projects.

For meaningful management of sedimentation in rivers and reservoirs, the basic requirement is to determine spatial soil erosion patterns and sediment yield of a catchment. If something cannot be measured it becomes difficult to manage. As in sedimentation studies, the accurate measurement of the quantities involved is not simple. In Pakistan, most of the small catchments in Pothowar region have no gauging stations, especially for sediment sampling. It is also very difficult to have detailed information about the topography, precipitation and other metrological parameters due to undulating terrain. For sustainable land and water management reliable predictions of sediment yield is necessary.

**Key Words:** Rawal dam, sediment modeling, SHETRAN

## 1. INTRODUCTION

Runoff is the catchment's response to precipitation resulting in stream flow. Runoff is extremely important as the landscape is changed by its erosive action. The volume of runoff depends upon watershed physical characteristics such as drainage area, elevation, slope, basin shape, land use, soil type, vegetation, topography, direction of orientation, drainage network patterns etc. When it rains in catchment area raindrop's impact and runoff's transport action causes erosion. Reliable prediction of runoff quantity and rate and sediment from land into rivers and streams is expensive, time-consuming and difficult (Pandey et al., 2008). In a watershed surface, runoff makes sediment available for transport. The amount of eroded material passing through a

Worldwide, different methods are being used for precise estimation of sediment yield. No single method can be applied globally because each method has certain limitations and the choice of method depends upon catchment characteristics (ecological considerations, dam engineering requirements, data availability, data requirements, time availability, and economics). Many mathematical models are in use and these models are based on different soil erosion and sediment yield estimation equations constituting different methods. Models are quite helpful to simulate erosion and sediment yield processes both spatially and temporally. During feasibility and detailed engineering design studies of a water resources project, numerical models are helpful for sediment yield analysis at temporal and spatial scale. Numerical models can help us to identify the sub-catchments having a major share of

sediment load into a reservoir or river. In this way, decision-makers and planners can devise techniques to manage sediment at specific catchment sites (sub-catchments). Catchment management techniques are directed towards reducing erosion at the specific problem areas. Numerical models can also analyze and investigate climate and human-induced changes over a required time period. As soil erosion and sediment transport are spatially distributed processes, so Geographic Information Systems (GIS) is considered to be quite useful for soil erosion estimation. GIS provides up-to-date, valuable spatial information on physical terrain parameters (Chowdary et al., 2004).

The designed gross storage capacity of the Rawal Dam was 47500 AF which has been reduced to around 31000 AF as per survey of 2009. This shows approximately 34 % reduction in storage is due to increased erosion in the watershed areas mainly due to urbanization process. In order to understand the soil erosion processes in the catchment, it is better to conduct mathematical modeling of the Rawal watershed. Physically based modeling systems have particular advantages for the study of basin change impacts and applications to basins with limited records. Physically-based models are based on physical and theoretical concepts. The models give a detailed description in time and space of the flow and transport processes that are involved in erosion and sediment yield. The overall objective of this study is to evaluate a physically based soil erosion model and its accuracy to predict catchment's sediment yield caused by water soil erosion.

According to Smithers and Schulze (2002), the vegetative canopy has marked effect on reducing the impact of rainfall on the land surface as if most of the rainfall is intercepted by a vegetative canopy, it eventually finds its way to the surface with much less energy as compared to direct rainfall. Various empirical erosion models account for vegetative canopy cover via taking into account different parameters. In MUSLE, the cover management factor (C), estimates the effect of ground cover conditions, soil conditions, and general management practices on erosion rates (Sadeghi et al., 2007). SHETRAN is a process-based, spatially distributed model system for determining water flow, contaminant migration and sediment transport (Lukey et al., 2010). SHETRAN uses an empirical equation to find out the soil erosion rate by raindrop and leaf drip impact by taking into account the rate of detachment of soil to the raindrop impact soil erodibility coefficient, the proportion of ground nearly shielded by ground cover, the proportion of ground shielded by the ground level cover and momentum squared of raindrop and leaf drip reaching the ground per unit time per unit area. SHETRAN solves physical based, governing, partial differential equations for transport and flow on a finite difference grid (Birkinshaw et al., 2010). According to Morgan et al., (1998), the soil detachability by raindrop impact can be uttered as the ratio of the weight of detached soil particles to a unit of rainfall energy. It has been observed that if there is knowledge about the amount of energy of a falling drop it will help in predicting the amount

of soil eroded from the ground with respect to different standard soil textures. The rate of detachment by raindrop impact as being proportional to the square of rainfall intensity (Beasley et al., 1980). Pidwirny and Sidney (2008) defined the process of entrainment as the lifting of the particle by the erosion agents and there is a slight difference between entrainment and detachment as it is somehow hard to distinguish between entrainment and detachment. The second one is mostly influenced by drag force of fluid. Pidwirny and Sidney (2008) stated that an entrained particle will not be deposited as long as the velocity of the medium is high enough to transport the particle horizontally. Following four different ways in which transport can occur in the transporting medium:

- The suspension which occurs in water, ice, and air is the state in which particles are carried by the medium without touching the surface of their origin.
- Saltation which occurs in air and water is the state in which particle moves from the surface to the medium in rapid nonstop recurring cycles. Their returning action to the surface generally has adequate force to cause the entrainment of new particles.
- Traction which occurs in all media of erosion sediment transport is the state in which there is a movement of particles by rolling, sliding, and shuffling along the eroded surface.
- The solution, a transport mechanism occurs only in an aqueous environment and it generally involves dissolving and carriage of the eroded material in water as individual ions.

Particle weight, shape, size, medium type and surface configuration are the main factors that decide which of the above processes operate (Pidwirny and Sidney, 2008). Julien (1998) stated that physical processes involved in the spatial and temporal variations of all the parameters describing upland erosion from local rainstorms and bank erosion processes exacerbate the complexity of quantifying sediment supply.

The sediment transported by the river has a varying diameter. It is possible to hydraulically determine the sediment yield in regions where the sediment transported is relatively coarse consisting of sand, gravel or coarser particles (Basson and Di Silvio, 2008). Sediment load is the quantity of sediment from a catchment passing through a river channel's mentioned point in a given interval of time. Sometimes total sediment load in a stream is used to express sediment quantitative analysis. The sediment transport capacity is determined as a function of the shape of the stream cross section and hydraulic conditions. A lot of attempts have been made to develop a relationship between the quantity of transport material available, sediment sizes and transport capacity.

Universal Soil Loss Equation (USLE) is one of the empirical equations developed for computing soil losses

(Wischmeier and Smith, 1965). Further improvements have been undertaken on the USLE method after which the Modified Universal Soil Loss Equation, MUSLE (Williams, 1975) and Revised Universal Soil Loss Equation, RUSLE were developed (Renard et al., 1991).

Sediment yield varies both in time and space. Knowledge regarding the temporal and spatial variability extent in sediment yields is important in resource provision for measures to sediment control. Guyot et al. (1994) conducted a study in the Rio Gran de, Bolivian Amazon drainage basin (Andean river) on sediment transport. It was observed that most of the transport occurs during three months of the year in which water flows are high in the river. The contribution of this period to the annual load is up to 90%. The factors which decide whether sediment yield increase or decrease are dependent on the site-specific conditions in accordance with time. A number of situations shows that annual sediment yield variability might be an indication of the precipitation and runoff variability.

Batalla and Sala (1994) studied the temporal variability of the suspended sediment load in a Mediterranean sandy gravel-bed river and observed that it was caused by seasonal effects, extremely high sediment concentration during individual floods and progressive exhaustion of sediment available to be transported during storm events sequences. The temporal variability in sediment yield is indicated by a cumulative plot of the observed sediment load which shows the slope in the graph of cumulative sediment discharge against the cumulative water discharge. It was also observed that the factors responsible for influencing the temporal variability of sediment yield also have the ability to affect sediment yield spatial variability to the extent where there is the possibility of spatial variability in the controlling variables within a catchment area. The temporal variation can be annual, seasonally and even inter-annually. It, therefore, highlights the need of long-term observed data for a detailed understanding of the sediment yield temporal variation and also to obtain sensible conclusions from observations.

Olive et al. (1994) stated that in the Murrumbidgee River, (New South Wales, Australia) most of the sediment was generated from one of the localized area tributaries and was transported through a short distance before being deposited in the reservoir up to the main Murrumbidgee River. This implies that the longest watercourse isn't essentially the major sediment source.

## 2. MATERIALS AND METHODS

### 2.1. Location, Climate, Hydrology, and Topography

Rawal Dam is situated in Pothowar plateau on Korang River, a tributary of Soan River. Its drainage area is 264 km<sup>2</sup> which fall in Murree, Rawalpindi, Abbottabad, and Hazara districts. Rawal Dam Coordinates are 33°-41' N latitude and 73°-07' E longitude. In Rawal watershed, slopes

are ranged from gentle to steep with an average of 240 ft per mile. The water in Korang River originates from rainfall and snowmelt, with major flows during the monsoon. The perennial flow in the river is of the order of only 3 to 6 cusecs. In the winter season, the flow is generally due to seepage. Average annual rainfall at Rawal Dam is 46.5 inches. The main precipitation occurs during monsoon season (July to September).



Fig 1. Location map of study area [right] and Rawal watershed [left]

## 2.2 Modelling of Catchment Erosion & Sediment Yield

### 2.2.1 Physically Based Models

Physically based models are based on the relationship between physical and theoretical controlling processes. These models simulate erosion and sediment yield both in time and space. The models give a detailed description in time and space of the flow and transport processes that are involved in erosion and sediment yield. Some of the available physically based models include: Water Erosion Prediction Project (WEPP) (Lafren et al. 1991), SHETRAN (Ewen et al. 2000), Hydrological Simulation Programme - Fortran (HSPF) (Bicknell et al. 1997), Areal Non-point Source Watershed Environmental Response Simulation (ANSWERS) (Beasley et al., 1980), Kinematic runoff and Erosion model (KINEROS) (Woolhiser et al., 1990), Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Kinsel, 1980), and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998).

### 2.2.2 The SHETRAN Model

Hydrological models are important tools for water and environmental resources management (Waseem et al., 2017). SHETRAN was developed from the Systeme Hydrologique European (SHE) a physically based spatially distributed (PBSD) modelling system for coupled surface and subsurface water flow in river basins. The SHETRAN model describes the catchment areas by using a grid and river networks and their links. It is a 3D model having a horizontal layer column underlying each grid square within each soil layer in the vertical direction. The layers show the thickness of soil and the top surface layer shows the overland surface. Flow is routed from surface, subsurface

and up to the channel or gullies (Ewen et al., 2000). SHETRAN model has following necessary modules: Frame module - The main body of the model and contains input parameters generally shared among various and allows all modules to perform synchronized activities. Evapotranspiration module - it calculates potential evapotranspiration from the soil, vegetation and water surfaces, evaporation from bare soil, wetted canopies, free water surfaces, dry channels and also computes transpiration by plants. Overland/channel module - it computes the surface water depth on the ground, in channels and calculates surface water flow across the ground surface and in channels. Variably saturated subsurface module - it simulates three-dimensional water flow in the subsurface soil scheme including seepage (Ewen et al, 2000).

## 2.3 Description of the Data

### 2.3.1 Metrological data

Precipitation and evaporation data was collected from Satrameel Meteorological station, situated in Rawal watershed. The data was available only on daily bases. The rainfall data was of good quality, while evaporation data was missing for a lot of years. Discharge data of Korang river was also available on monthly bases. At dam site, there was no mechanism for systematic measurement of discharge data on daily bases and there was a lot of ambiguities in the data.

### 2.3.2 Sediment Data

At the dam site, there was no mechanism for systematic measurement of sediment data. So, sediment data was not available for the dam site. The only type of sediment data available was in the form of Hydrographic surveys (Sedimentation surveys). In order to generate sediment data, the Rawal lake survey range lines were digitized for the year 1996 and 2000 using ArcGIS software. After digitizing the maps, the surface volume was compared at different levels to have the volume of deposited sediment in last four years.

## 2.4 Generation of Digital Maps of Hydrographic Survey

For digital map generation, the range lines survey of years 1996 and 2000 were digitized by ARC GIS. After developing digital maps for years 1996 and 2000, the volume at different elevations were calculated using 3D Analyst Tool > Surface Analysis > Area and Volume command. Then volume difference at same elevations was calculated for years 1996 and 2000 that gives change in volume of the reservoir with the passage of time.

## 2.5 Data Processing and Analysis

### 2.5.1 Rainfall-Runoff Analysis

For the year 2001, 2002, 2004 and 2005, rainfall and runoff data were analyzed by drawing it on same graph

with inflow (Runoff) and rainfall data on primary and secondary Y-axis respectively and time in months on X-axis. For the year 2001, the graph shows a good relationship between the inflow and the rainfall as both rainfall and inflow peaks were observed in the same month.

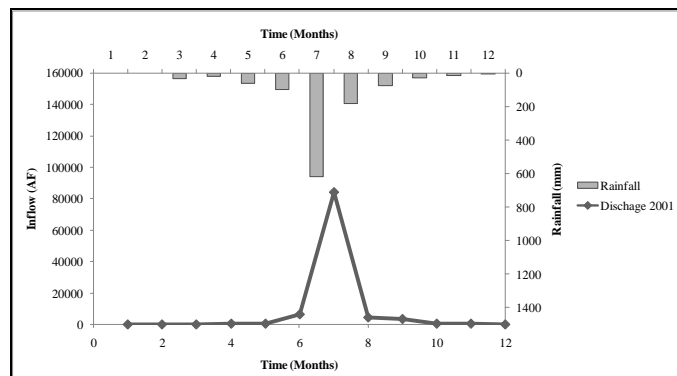


Fig 2. Rainfall-runoff comparison 2001

For the year 2002, the graph (Fig. 3) also shows a good relation between the inflow and the rainfall as in the 8th month the peak runoff and rainfall was observed.

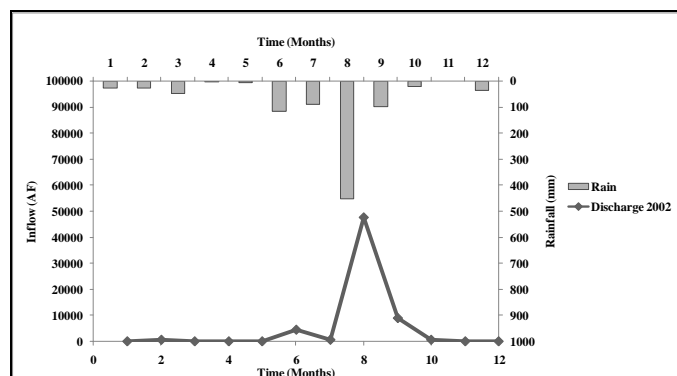


Fig 3. Rainfall-runoff comparison 2002

Similarly, the graph (Fig 4) also shows a good relation between the inflow and the rainfall for the year 2004. As both rainfall and inflow peaks were observed in the same month i.e. August.

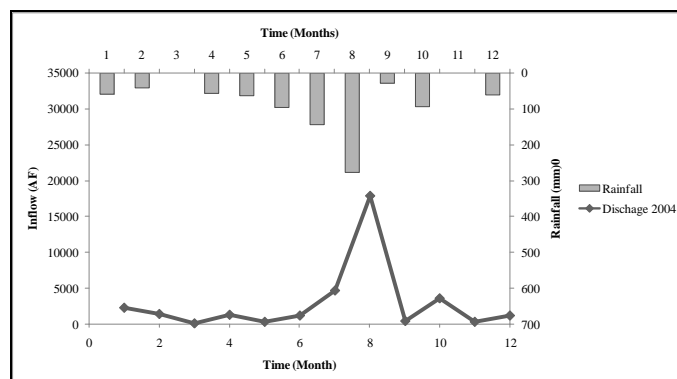


Fig 4. Rainfall-runoff comparison 2004

For the year 2005, the graph (Fig. 5) showed that in comparison to three rainfall peaks there are only two runoff peaks. It indicates that there is a problem with discharge data for this year.

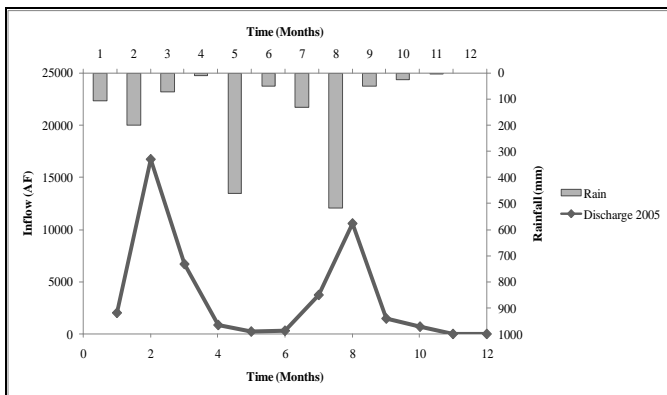


Fig 5. Rainfall-runoff comparison 2005

### 2.5.2 Rainfall-Runoff Ratio

Rainfall-runoff ratios for the years 2001, 2002, 2004 and 2005, were calculated by adding up the monthly rainfall volume and then runoff volume was converted into depth (mm) by dividing it with the catchment area.

### 2.6 Topographic Analysis for DEM Extraction

Rawal watershed DEM was extracted by using Arc hydro tools in a specified manner in ArcGIS software. The Rawal DEM obtained is shown below.

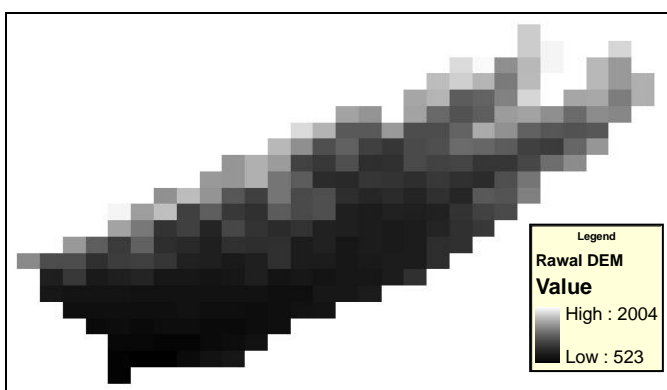


Fig 6. Rawal Watershed DEM

### 2.7 Results Analysis

Model output was in the hourly form. As the available runoff and sediment data were in form of monthly data, the hourly data was summed up into monthly data by using excel. The results were then compared to have a good simulation. After a good simulation was achieved then the model output was evaluated through coefficient as COE and PBIAS.

The coefficient of efficiency (COE) or Nash-Sutcliffe efficiency (NSE) is the statistical criterion for evaluation of goodness of fit between observed and calculated values. Nash-Sutcliffe efficiencies range from Infinity to 1. Essentially, the closer to 1, the more accurate the model is, equal to 1 corresponds to a perfect match of modeled to the observed data, equal to 0 indicates that the model predictions are as accurate as the mean of the observed data and in range of  $-\infty < NSE < 0$ , indicates that the observed mean is a better predictor than the model. The coefficient of model efficiency (COE) was calculated (Nash- Sutcliffe, 1970) as:

$$COE = 1 - \frac{\sum_{i=1}^N (S_i - O_i)^2}{\sum_{i=1}^N (O_i - \bar{O})^2}$$

Where

$S_i$ = Simulated value

$O_i$ = observed value

$\bar{O}$  = Mean Observed

Percent bias (PBIAS) measures the average tendency of the simulated values to be larger or smaller than their observed ones. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate model underestimation bias. Percent bias (PBIAS) was calculated (Yapo et al. 1996) as.

$$PBIAS = 100 \frac{\sum_{i=1}^N (S_i - O_i)}{\sum_{i=1}^N O_i}$$

Where

$S_i$ = Simulated value

$O_i$ = observed value

## 3. RESULTS AND DISCUSSION

### 3.1 Model setup

The total catchment area is 264 km<sup>2</sup>, which was represented by 264 grid squares of 1km by 1km each. The elevations ranged from around 2258 masl (highest point) to 393 masl (lowest point). The dominant soil type within the catchment is clay-loam. The main type of vegetation is forest. Major land uses are forest and urbanization. The canopy and leaf parameters such as canopy drainage, canopy storage and vegetation cover indices were based on standard parameters specified in SHETRAN Version 4 User Guide (2008) for various standard vegetation types. The Manning's roughness coefficient for channels was taken as 0.035 (Strickler resistance coefficient as 29).

### 3.2 Flow calibration

Upon setting up the appropriate hydrological, meteorological, spatial data, the model was calibrated against observed flow for the year 2001. The most significant

hydrological and flow calibration parameters that were slightly adjusted included the following: Stickler's overland flow coefficient, vegetation parameters (canopy storage capacity (mm), leaf area index, saturated conductivity and unsaturated conductivity and soil depths. Daily rainfall and evaporation data were used with the data time step of 24 hours. The output from the model was hourly flow data. The hourly data was then converted into monthly data for comparison with the observed flow. The accuracy of the calibration was verified by comparing the simulated flows with observed flows as shown in fig 7. The  $R^2$  was found to be 0.82. For calibration results COE and PBIAS coefficients were calculated to be 0.98 and -2 respectively, which showed satisfactory model performance.

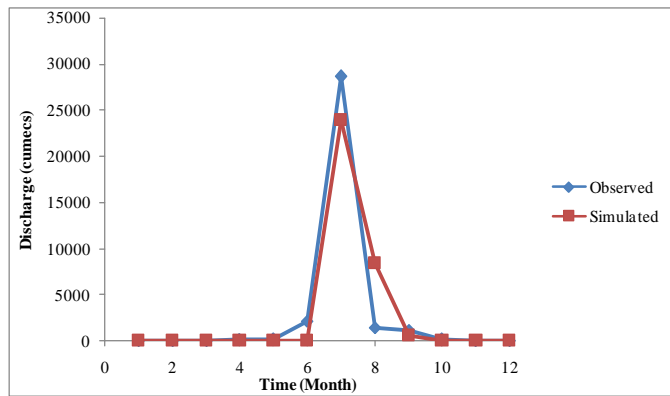


Fig 7. Flow Calibration for year 2001

As the results were obtained a comparison of observed and simulated values were made to obtain a correlation between them. Observed data was plotted on X-axis while the simulated data was plotted on Y-axis. After plotting the data, best fit trend line was selected and its value of  $R^2$  was noted. For year 2001 it was observed that there was high flow in only one month while in rest of the months the flow was low. This is the reason that most of the values on graph gather at the bottom left of the graph and only one value is seen away from this mob of values.

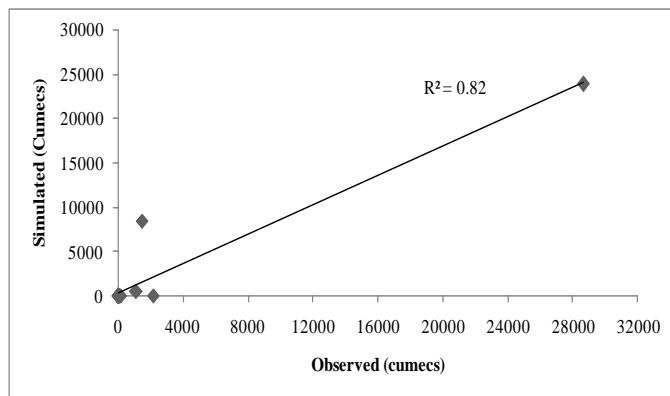


Fig 8. Comparison of observed and simulated discharge for year 2001

### 3.3 Flow validation

After calibrating the model, it was validated for year data 2002, 2004 and 2005. As mentioned earlier there was problem with data as the observed data was of poor quality. When rainfall-runoff analysis was done for year 2003 it was observed that the months having high rainfall don't have high flows and vice versa. Similarly, for 2003 the validation comparison of observed and simulated data was very poor. For year 2002 the model validation results were quite good. The  $R^2$  value of best fit trend line was found to be 0.83. The observed and simulated data values were used for calculating COE and PBIAS coefficients which turned out to be 0.97 and -8.

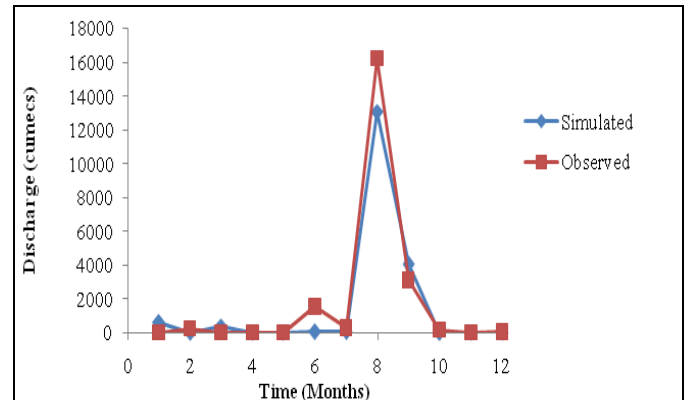


Fig 9. Flow validation for year 2002

The simulated results for year 2002 were compared with the observed one to determine the  $R^2$  value which was observed to be 0.83. Only two points can be seen to have maximum values while for rest of the months the values are mobbed near the point of origin.

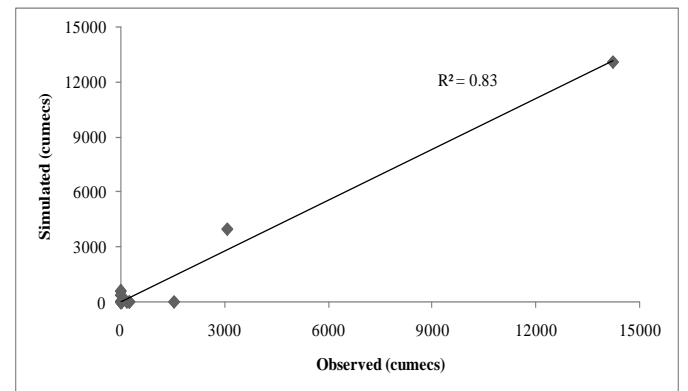


Fig 10. Comparison of observed and simulated discharge for year 2002

For year 2004 the model results were also quite good. The model calculated the peaks in same months in which the peaks were observed. The  $R^2$  value was found to be 0.92.

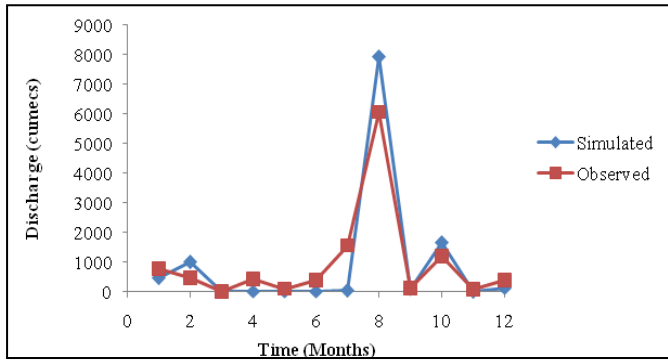


Fig 11. Flow validation for the year 2004

In the comparison graph for the year 2004, seven values mobbed around the point of origin while the rest scattered around the trend line. The coefficients values for COE and PBIAS were calculated to be 0.93 and 7.

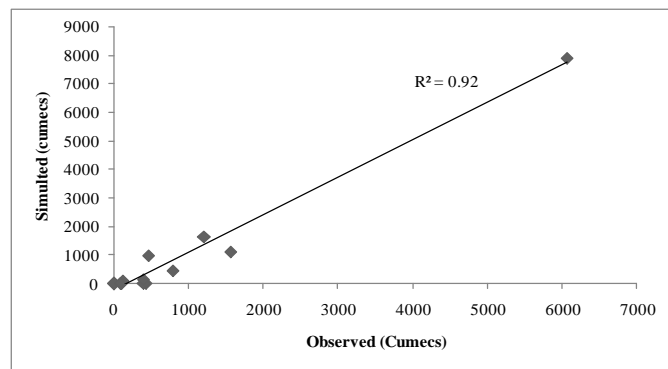


Fig 12. Comparison of observed and simulated discharge for the year 2004

For the year 2005 the simulated value showed one peak while the observed data showed two peaks. But the annual runoff volume was quite close to the annual observed data.

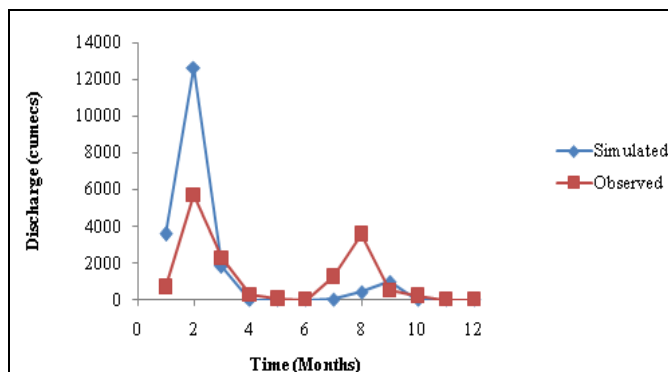


Fig 13. Flow validation for the year 2005

The comparison graph for the year 2005 showed six-month values mobbed around the origin while the rest scattered around the trend line. The R2 value was observed to be 0.83. The values for COE and PBIAS coefficients were calculated to be 0.86 and 14.

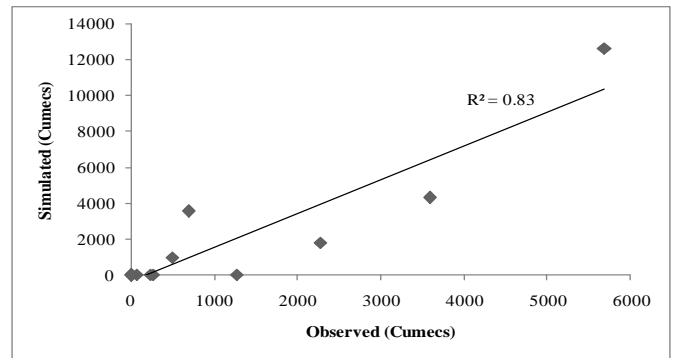


Fig 14. Comparison of observed and simulated discharge for the year 2005

After validating the model, the input files for SHETRAN standard are written and the output shegarph file is also generated which is viewed using HDF software. In shegarph file, catchment map shows elevation and river network pattern in the catchment area.

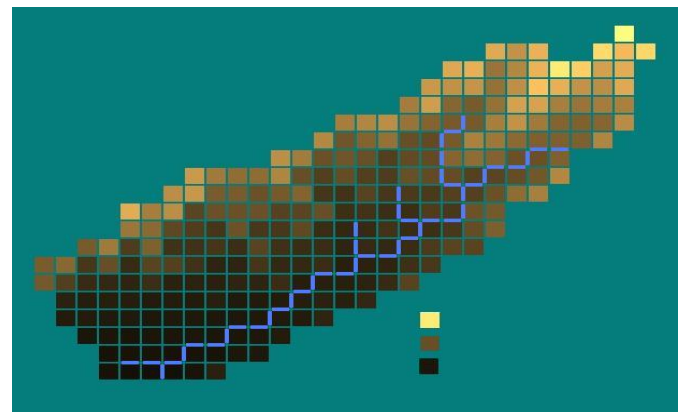


Fig 15. SHETRAN generated Rawal catchment palette showing elevation and rivers as links

### 3.4 Sediment Calibration and Validation

After getting a reasonable flow simulation the SHETRAN Standard input files were written using write Shetran input files tool. The sediment file is not generated by the above command. The sediment file was manually written as it has to be manually generated for each catchment according to the catchment characteristics. The check visualization plan file was also adjusted in order to achieve the required results. Sediment calibration was done for the year 2001 by comparing the model results from the results of hydrographic survey digitization. After obtaining a good calibration the model was validated for years 2002, 2004 and 2005. The model output was on hourly bases; it was converted into monthly bases by using excel. The parameters used in sediment file are given below.

Table 1. Soil parameters used in Sediment file

| Parameter  | Average/range   |
|--|---|
| Overland flow soil erodibility                           | $1.3 \times 10^{-12}$ to $7 \times 10^{-11} \text{kgm}^{-2}\text{s}^{-1}$ |
| Raindrop and drip soil erodibility                       | 0.1j-1  |
| Threshold depth of loose soil over which erosion is zero | 0.05m   |
| Channel bank erodibility coefficient                     | $1 \times 10^{-11} \text{kgm}^{-2}\text{s}^{-1}$                          |

\* rate of detachment of soil per unit area.

### 3.4.1 Sediment Load Calibration

SHETRAN Standard model sediment load calibration was done for the year 2001. The model parameters were varied such that the model output is close to the calculated sediment data. The model output was on hourly bases it was converted into monthly bases. The results are shown in fig 16 The results were then used to calculate the COE and PBIAS coefficients which were 0.94 and -5.8 respectively. The results showed that model performance was satisfactory.

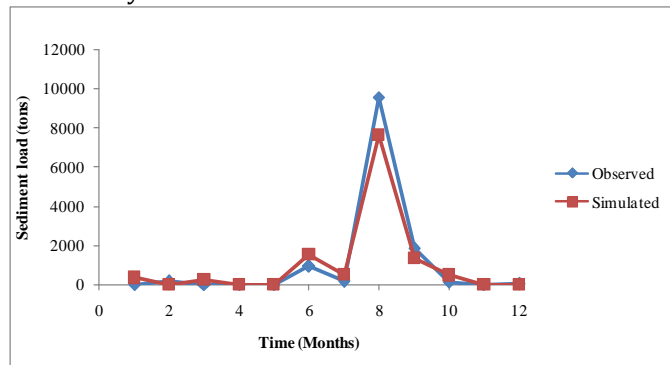


Fig 16. Sediment load Calibration 2001

The cumulative graph was also drawn as shown in fig 17. The total simulated sediment load was 17816 tons and the observed load was 19976 tons.

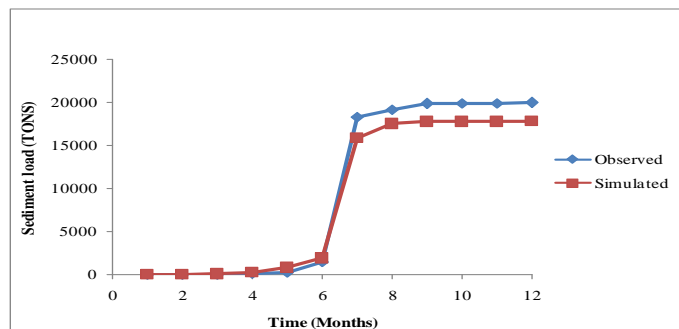


Fig 17. Observed and Simulated sediment load cumulative graph 2001.

### 3.4.2 Sediment Load Validation

The model was validated for the year 2002. The parameters used in calibration were kept same for calibration purpose. The model output was hourly sediment discharge. The model output was compared with the sediment data calculated by using the developed correlation. The comparison between model-simulated and calculated sediment load is shown in Fig. 18. It can be seen that the simulated and calculated curves match well except for few months. The correlation coefficient was 0.97 while the COE and PBIAS were 0.96 and -6 respectively, which showed that model performance was satisfactory.

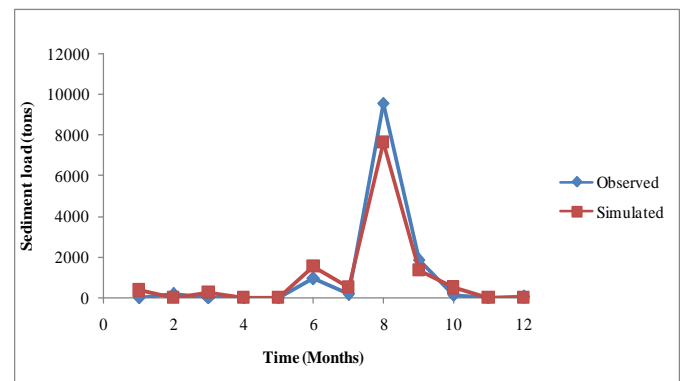


Fig 18. Sediment Validation 2002

The cumulative graph was also drawn as shown in fig 19. The total simulated sediment load was 12151 tons and the calculated load was 12767 tons.

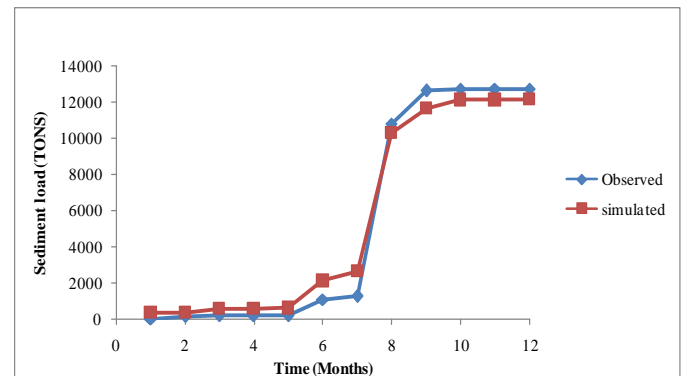


Fig 19. Observed and Simulated sediment load cumulative graph 2002

After model validation, it was applied to the year 2004. The results depicted that model overestimates the calculated results. PBIAS coefficient with a value of 12 also shows that model overestimates the results. The COE value was calculated to be 0.98 which suggested that model performance was satisfactory.



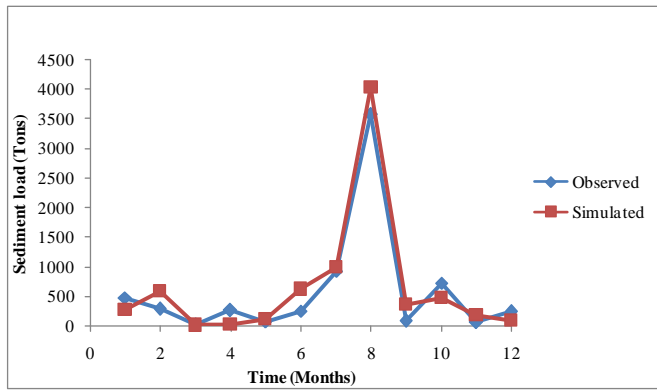


Fig 20. Model Application 2004

The cumulative graph was also drawn as shown in fig 21. The total simulated sediment load was 7738 tons and the calculated load was 6889 tons, which showed that model overestimates the results.

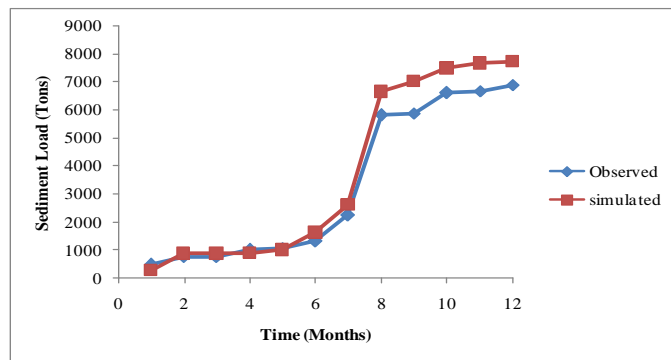


Fig 21. Observed and Simulated sediment load cumulative graph 2004

The model was also applied to the year 2005. The results obtained showed that the model somewhat overestimates the results. This is because of the poor quality of data. The COE and PBIAS coefficients were calculated to be 0.96 and 16 respectively.

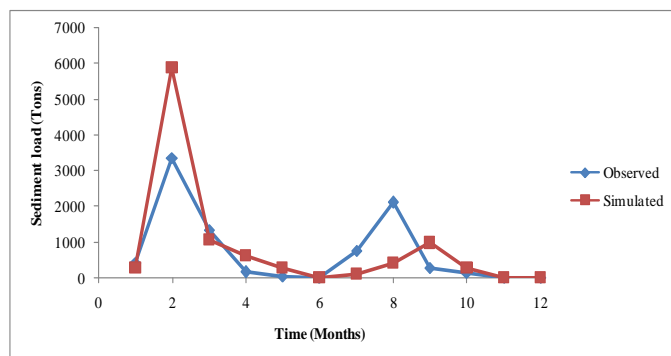


Fig 22. Model Application 2005

The cumulative graph was also drawn as shown in fig 23. The total simulated sediment load was 10055 tons and observed load was 8639 tons which showed that model overestimates the results.

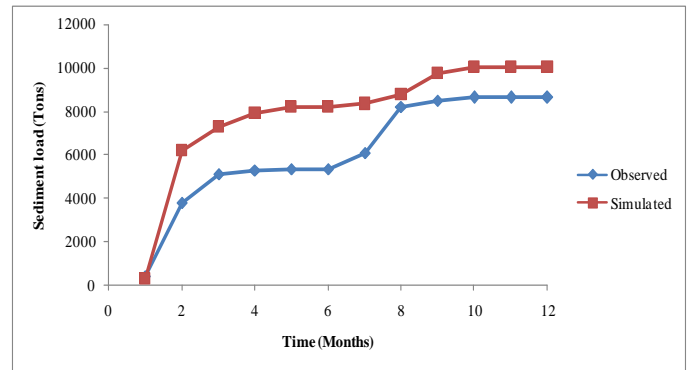


Fig 23. Observed and Simulated sediment load cumulative graph 2005

### 3.5 Land Use Sensitivity Analysis

Sensitivity analysis for land use parameters was done by changing the vegetation types. The major type of land use in the catchment is forest i.e. 48%. The sensitivity of sediment yields to increase or decrease in forest area was checked. The results were found reasonable, as an increase in forest area showed a decrease in sediment yield while a decrease in forest area resulted in an increase in sediment yield. The decrease in sediment yield was calculated to be from 75 tons/Km<sup>2</sup> to 62 tons/Km<sup>2</sup>. It was observed that for 10 % increase in forest area sediment yield decreased up to 17%. On the other side, 10 % decrease in forest area resulted in 12% increase in sediment yield i.e. from 75 tons/Km<sup>2</sup> to 84 tons/Km<sup>2</sup>. Further investigation should be done based on results to find the best effective watershed management technique for controlling erosion.

Table 2. Land use sensitivity of sediment yield in terms of forest area

| Status of Forest Area | Forest area (%) | Sediment yield (tons/Km <sup>2</sup> ) |
|-----------------------|-----------------|--|
| Present               | 48              | 75                                     |
| Increased             | 58              | 62                                     |
| Decreased             | 38              | 84                                     |

### 4 Conclusion

Following conclusions have been drawn from the results of this study;

- The flow simulation yielded satisfactory results. Peaks flows were observed generally during the monsoon period, while in the rest of the months the flows were quite low as compared to peak flow.
- For the year 2005 rainfall runoff comparison graph showed the observed data was of poor quality, as the months in which peak rainfall was recorded did not have peak runoff and vice versa.

- The sediment modelling calibration was done against the sediment data which was actually generated from the relation to runoff and sediment.
- The sediment modelling results were quite accurate. This was due to the fact that the calculated sediment data was used for calibration and validation purpose as there was no observed sediment data.
- The mean annual sediment load was calculated to be 45 tons/Km<sup>2</sup>.
- The model sensitiveness to land use change was also checked and it was concluded that the model responds reasonably to catchment land use changes.
- In the reservoir on the right side of dam, a deposition pattern was observed while on the left side there was no deposition pattern.

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