Optimizing Micro Watershed Management for Runoff Harvesting, Natural Resource Conservation at Various Slope Gradients and Vegetative Covers using SWAT Modeling Approach

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1 Summary

A study was undertaken to evaluate the soil erosion parameters using semi-distributed basin scale SWAT model in different watersheds of Chakwal and Attock districts. The model was calibrated and validated for a small watershed without any soil conservation structures. For this purpose four sub-catchments of Dhrabi watershed were selected and model setup was done using Arc SWAT interface for each sub-catchment independently.

SWAT Manual Calibration helper tool was used for calibration of the model parameters using time series (monthly) sediment load data from 2009-2010 and then validation of simulated sediment yield was done for the year 2011 for each sub-catchment separately. The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the sediment yield for the study area.

The correlation coefficient value was 0.78 between simulated and observed sediment yield data for combined sub-catchments and the coefficient of determination (R^2) and NSE values obtained were above 0.80 and 0.70, respectively for the calibration period and 0.70 and 0.65, respectively for the validation period for each sub-catchments.

The sensitivity analysis on five sediment yield producing parameters was carried out and results show that USLE_P is most sensitive parameter and its value ranged from 0.11 to 0.89 and other parameters were SPEXP, SPCON, USLE_C, and USLE_K and value used ranged from 1.0 to 1.33, 0.0032 to 0.007, 0.164 to 0.192 and 0.211 to 0.2537, respectively and sensitivity of these parameters decreased simultaneously and value of USLE_LS factor ranged from 2.36 to 2.46 combined for all four catchments.

After calibration and validation, the SWAT model was applied to following sites for estimating the soil erosion in watersheds with water conservation structures. The following sites were modeled using SWAT model:

1. Kohkar Bala
2. Khandoa
3. Dhoke Mori (Khaliq Gulli, Ashraf Gulli)
4. Chak Khushi

5. Dhok Dhamal
6. Dhok Hafiz Abad

The sites 1 to 4 are located in District Chakwal, whereas sites 5 and 6 are situated in District Attock. The model was applied for six years from Jan 2010-April 2015. The options for model application out scaling to whole district of Chakwal and Attock are suggested based on the topographic data and slope classification. It was estimated that about 61% (3918 km^2) area of District Attock lies in slope range 0-4%, whereas 28% (1786 km^2) area lies in slope range of 4-10%. Similarly in district Chakwal 60 % area (4095 Km2) have slope 0-4% and 28% area (1913 Km2) lies in slope range 4-11%.

In district Chakwal minimum sediment yield reduction varied between 2,220 T/y and 122,850 T/y and maximum reduction was 145,500 T/y to 794,4300 T/year, whereas in Attock minimum sediment yield reduction was 106,700 T/y and maximum reduction was 7600790 T/y (Table 13.6). Keeping in view topographic conditions there is huge potential for implementation of soil conservation practice by installation of stone structures. It is concluded that there is huge potential for soil conservation adoption in District Attock

The overarching findings of the study are that SWAT model gives good results of sediment yield/soil erosion and that this model can be used for rocky mountainous watersheds for erosion control and watershed management.

2 Introduction

Water and soil are the most important and basic natural resources for agriculture and livestock production which play a key role in economic growth of any region. Research studies have shown that agricultural soils develop from wind and water transported material comprising of alluvial deposits; mountain washed out and stream valley deposits etc. However, when this balance i.e. fertile soil formation, is disturbed by anthropogenic activities then the sediment yield is dramatically increased at the expense of soil renewal and causes a serious threat to water resources development.

Globally, deteriorating water resources are a growing concern and it has been estimated that due to soil erosion the productivity loss in drylands range from US$13 billion to US$28 billion annually (Scherr and Yadav, 1996). Urbanization, deforestation, overgrazing, improper tillage practices, leaving the land fallow and low organic matter are the major causes of soil erosion and produced the serious economy loss to the nation (Ashraf et al.,2002).

Recently, modern tools such as soil erosion estimation modeling can be applied using different techniques such as empirical models, physical based models and conceptual models etc. at watershed level but empirical models such as the USLE are still used because of their ease of application and low data requirements but it is not able to simulate physical processes in a watershed. In contrast, physically-based models like WEPP provide detailed understanding and quantification of the processes, but they require a large amount of data and are usually applied to small watersheds with areas ranging between 10 and 100 km^2 (Kliment et al. 2008).

Conceptual models like SWAT (Soil Water Assessment Tool) represent a compromise between these two model types by combining empirically-derived algorithms with physically-based ones (Borah and Bera 2003). So, SWAT is more suitable as a tool for testing effectiveness of sustainable water resources management practices in watersheds dominated by agriculture.

Studies show that the top soil is being lost at least 16 times faster than it can be replaced and this continuous and rapid loss of nutrient-rich top soil eventually leads to desert-like situation by making conditions unsuitable for vegetation growth. Soil erosion causes not only onsite degradation of agricultural land, but also off-site problems such as the downstream deposition of sediment in fields, floodplains, and water bodies. Land degradation resulting from erosion is one of the most important issues in the rainfed areas and in order to access the magnitude of problems due to soil erosion it is necessary to keep track of quantitative data on the extent and actual soil erosion rate for better and reasonable solution of these problems (IAEA, 2004).

Rainfall, landuse, soil and topographic data along with other climatic and metrological data are the key parameters for modelling the sediment yield of any watershed, but assessing and mitigating soil erosion at the watershed level is complex - both spatially and temporally, due to erratic and unpredicted nature of rainfall, climatic variability, heterogeneities in topography, land cover and other catchment features for specified areas under study. Hence, watershed models that are capable of capturing these processes in a dynamic manner are needed to be provide an enhanced understanding of the relationship between hydrologic processes, erosion/sedimentation, and management options. Estimation of sediment yield of any catchment using soil erosion modeling is the basis of integrated water resource management which is necessary for solving practical problems, flood protection measures and design of water related structures.

This study focused on the Pothwar area (Districts of Chakwal and Attock) where high intensity rainfalls, steep slopes, and erodible soils without adequate protection have led to extensive soil erosion and consequences are devastating including loss of fertile soil, loss of vegetation, reservoir depletion by sedimentation, and eutrophication and contamination of surface and groundwater. Highest recorded rate of erosion in the area is estimated to be 150-165 tons per hectare per year (Ashraf et al., 2002). The texture mostly varies from sandy to silt loam and clay loam comprising of poor to fertile lands. The plateau has a flat to gently undulating surface broken by gullies and low hill ranges.

Due to climatic variability, the rainfall pattern in this region is unpredictable with respect to time which causes severe erosion and impacts surface water resources. The severe erosion produces high sediment yield causing failure of soil and water conservation structures such as small dams and water ponds.

Therefore, management techniques practiced to conserve soil and water are not only related to the conservation of natural resources, but also to the sustainable development of the agricultural sector. In order to formulate management practices, effective soil erosion management must be considered. Soil loss from a watershed can be estimated based on an understanding of the underlying hydrological process, climatic conditions, landforms and soil factors. High sediment yields are natural in upland plateau of Pothwar area due to the high rates of erosion and soil production. When this balance is disturbed by anthropogenic activities, the sediment yield is dramatically increased at the expense of soil renewal. This rise in soil erosion and sediment yield in Pothwar area has endangered soil and water conservation structures, reservoir projects and caused doubts about the viability of existing and future schemes. Untimely sedimentation may reduce the benefits and, if it is ignored, remedial measures may become prohibitively expensive. Keeping in view such problems, estimation of sediment yield and evaluation of soil erosion parameters were done in Pothwar area on the Dhrabi watershed using semi distributed Soil and Water Assessment Tool (SWAT) tool.

3 SWAT Model Description

SWAT is a conceptual basin scale, semi-physical, semi-empirical continuous-event based, daily and hourly time step hydrologic semi distributed long term simulation model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Arnold et al., 1998, 2000; Neitsch et al. 2001). It can also be used to simulate water and soil loss in agriculturally dominated small watersheds (Tripathi et al. 2003).

Watersheds are divided into sub-watersheds based upon drainage areas and each sub watershed is further divided into Hydrological Response Units (HRUs) based on land cover and soil type. Each HRU is assumed to be spatially uniform in land use, soil, topography, and climate. SWAT requires specific information about weather, soil properties and topography, vegetation, and land management practices occurring in the watershed. A full description of SWAT can be found in the theoretical documentation by Neitsch, et al. (2001).

3.1 Modelling Sediment Yield in SWAT

Erosion and sediment yield in SWAT are computed for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977). MUSLE uses the amount of runoff to simulate erosion and sediment yield while the USLE uses rainfall as an indicator of erosive energy. MUSLE is expressed in terms of runoff volume, peak flow, and Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) factors. The hydrology model supplies estimates of runoff volume and peak runoff rate, which, with the sub-basin area, are used to calculate the runoff erosive energy variable. The modified universal soil loss equation adopted in SWAT is given out in the following mass balance equation:

$$\mathrm{S.Y} = 11.8\,\left(\mathrm{Q_{surf}} \times \mathrm{q_{peak}} \times \mathrm{area_{hru}}\right)^{0.56}.\,\mathrm{K_{USLE}}.\,\mathrm{C_{USLE}}.\,\mathrm{P_{USLE}}.\,\mathrm{LS_{USLE}}.\,\mathrm{CFRG}$$

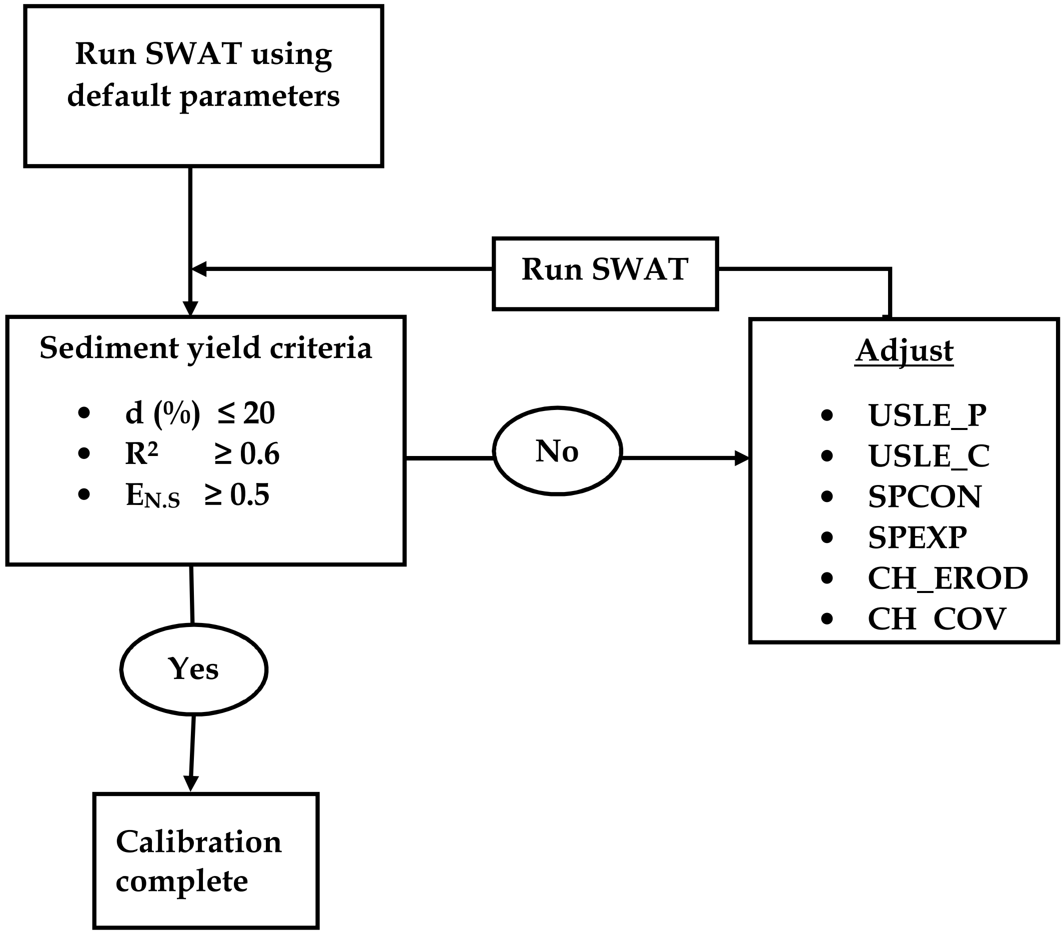
where S.Y is the sediment yield (tons/day), Q_{surf} is the surface runoff (mm/ha), q_{peak} is the peak runoff rate (m^3/sec), $area_{hru}$ is the area of hydrological response unit (ha), K_{USLE} is the soil erodibility factor, C_{USLE} is the management cover factor, P_{USLE} is the support practice factor, LS_{USLE} is the topographic factor and CFRG is the coarse fragment factor.

The most sensitive soil erosion evaluation parameters which are used in Arc SWAT are listed below in table 3.1

Table 3.1: Soil erosion evaluation parameter used in Arc SWAT

Parameter	Description
USLE_P	USLE practice factor
USLE_C	Cover and management factor in USLE
USLE_K	USLE Soil erodibility factor
SPCON	Linear parameter for calculating the maximum amount of sediment that cab be re-entrained during channel sediment routing
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing
CH_EROD	Channel Erodibility factor
CH_COV	Channel Cover factor

An iterative approach is usually used for manual calibration involving the following steps: (1) perform the simulation; (2) compare measured and simulated values; (3) assess if reasonable results have been obtained; (4) if not, adjust input parameters based on expert judgment and other guidance within reasonable parameter value ranges; and (5) repeat the process until it is determined that the best results have been obtained.



LEGENDS

d: percent difference between measured and simulated average values
R^2: Coefficient of determination
$E_{N.S}$: Nash-Sutcliffe efficiency coefficient
USLE_P: USLE practice factor
USLE_C: USLE Cover & Management factor
SPCON: Linear coefficient for with in channel sediment routing
SPEXP: Exponent coefficient for sediment re-entrained in channel sediment routing
CH_EROD: Channel erodibility factor
CH_COV: Channel cover factor

Figure 3-1: SWAT manual calibration flowchart for sediment yield (from Engel et al., 2007; adapted from Santhi et al., 2001)

4 Study Area for Model Calibration and Validation

The study was conducted in the Dhrabi Watershed - an area of 196 km^2 which is located between latitudes 32°42′36″N and 32°55′48″N and longitudes 72°35′24″E and 72°48′36″E in District Chakwal, Pothwar Pakistan. Four small watersheds were selected in this region for this study. Reasonably accurate data on rainfall, landuse, soil texture and sediment yield was readily available for the selected watersheds from past field studies.

The watershed consists of low to medium hills between elevations of 445 to 898 meters above sea level. The source of elevation information was Digital Elevation Models (DEMs) of the study area. The topography varies from shallow to deep gullies, small to large terraces, and mounds to hillocks. The soil is predominantly of a sandy loam type and low in organic matter (less than 1%). The study was conducted from 2013 to 2015. The location map of the area is shown in Fig.4.1.

To determine the degree of soil erosion, sediment yield was measured from the four sub-catchments in the watershed because catchments have well-defined boundaries and are fully representative of study area. These catchments consisted of gully and terraced land-use systems. The salient features of the catchments are given in Table 4.2 and topographic maps and landuse maps are provided in Fig.5.2 and 5.3. The soil texture class of these catchments is sandy loam and rainfall ranges from 450 mm to 630 mm with high spatial and temporal variation. Over 60 % rainfalls occur in June and September months.

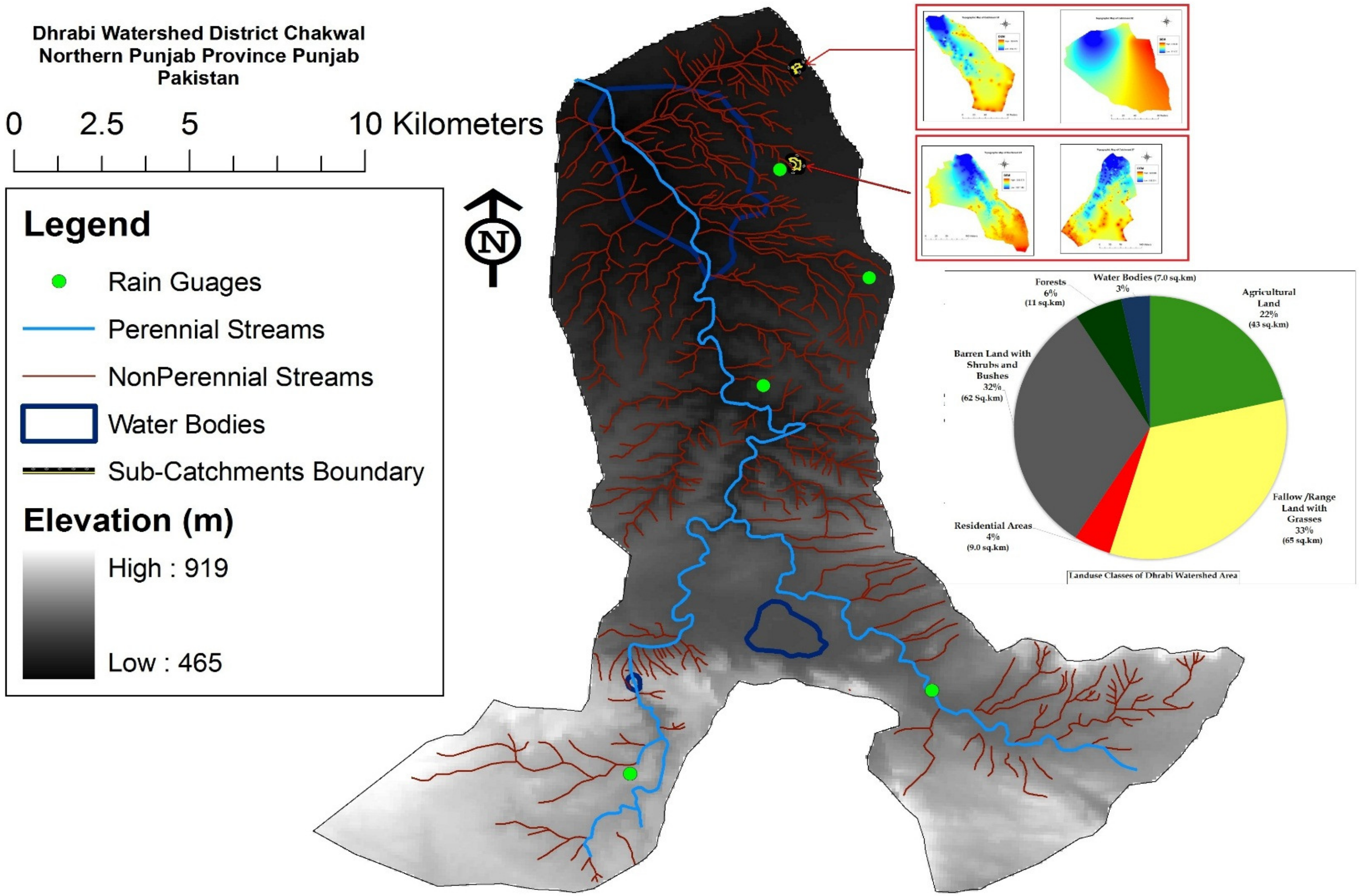


Figure 4-1: Location of study area in Dhrabi watershed of Pothwar Area

Table 4.1: Salient features of sub-catchments

Catchment ID	Soil type	Landuse classification	Area of catchment (ha)
25	Sandy Loam	Trees, Grasses, Bushes, Shrubs, Pastures for Grazing, Winter wheat, Agricultural Land	2.0
27	Sandy Loam	Trees, Grasses, Bushes, Shrubs, Pastures for Grazing, Winter wheat, Agricultural Land	3.0
31	Sandy Loam	Trees, Grasses, Bushes, Shrubs, Pastures for Grazing, Winter wheat, Agricultural Land	1.5
32	Sandy Loam	Trees, Grasses, Bushes, Shrubs, Pastures for Grazing, Winter wheat. Agricultural Land	3.3

5 Material and Methods

5.1 Model Set-up

The first step in setting up of SWAT model on any study area is the physiographic analysis based on catchment topography. ArcSWAT automatically delineates a watershed into sub watersheds based on Digital Elevation Model (DEM) to account for catchment heterogeneities. For this study, four sub catchments of similar characteristics were selected for the evaluation of sediment yield in Dhrabi watershed so physical topographical survey of these sub-catchments were conducted using GPS and then DEM of these sub catchments were generated using point source elevation data as shown in figure 4. DEM of each sub-catchment was supplied to the ArcSWAT for topographic analysis, delineation of sub-watershed and stream network generation.

In this case the whole sub catchment was divided into individual sub-basins. Successful execution of terrain processing module of ArcSWAT interface resulted in generation of appropriate database for the sub-basin parameters and a detailed topographic report of the watershed. Land use and soil map along with their respective look-up tables prepared earlier were supplied to the model for reclassification according to SWAT coding convention. Further, entire watershed was classified into three slope categories using the interface. Shapefiles of all three maps were then overlaid in GIS to create HRUs with unique land cover/soil and slope class. Subdividing the areas into HRUs enables the model to reflect the evapotranspiration and other hydrologic conditions for different land cover/crops and soil.

Location table of weather stations, daily precipitation files, maximum and minimum temperatures, wind speed, relative humidity, solar radiation data were loaded to link them up with the required files already created for the purpose. After loading all the input data and generating the required database files, SWAT model was initially run on monthly basis using default parameter values.

Table 5.1: Model input data source

Data Type	Source	Data description and properties
Topography (DEM)	Surveying using GPS (SAWCRI, Chakwal)	Digital Elevation Model (1m×1m) resolution of four sub-catchments
Soil map	Soil textural analysis by SAWCRI, Chakwal	Physical properties of soil, i.e. sandy loam soil
Landuse map	Google Earth	Classification based upon Google Earth survey
Climate data	Automatic weather station and water level recorder installed in different sub- catchments by SAWCRI Chakwal	Daily data of precipitation, temperature, wind speed, relative humidity, solar radiation and flow data
Sediment data	An experimental setup for measurement of sediment load of each catchment by SAWCRI Chakwal Department.	Event-based sediment data

A line diagram given in Figure 5.1 provides the procedure for simulation of sediment yield using Arc SWAT tool.

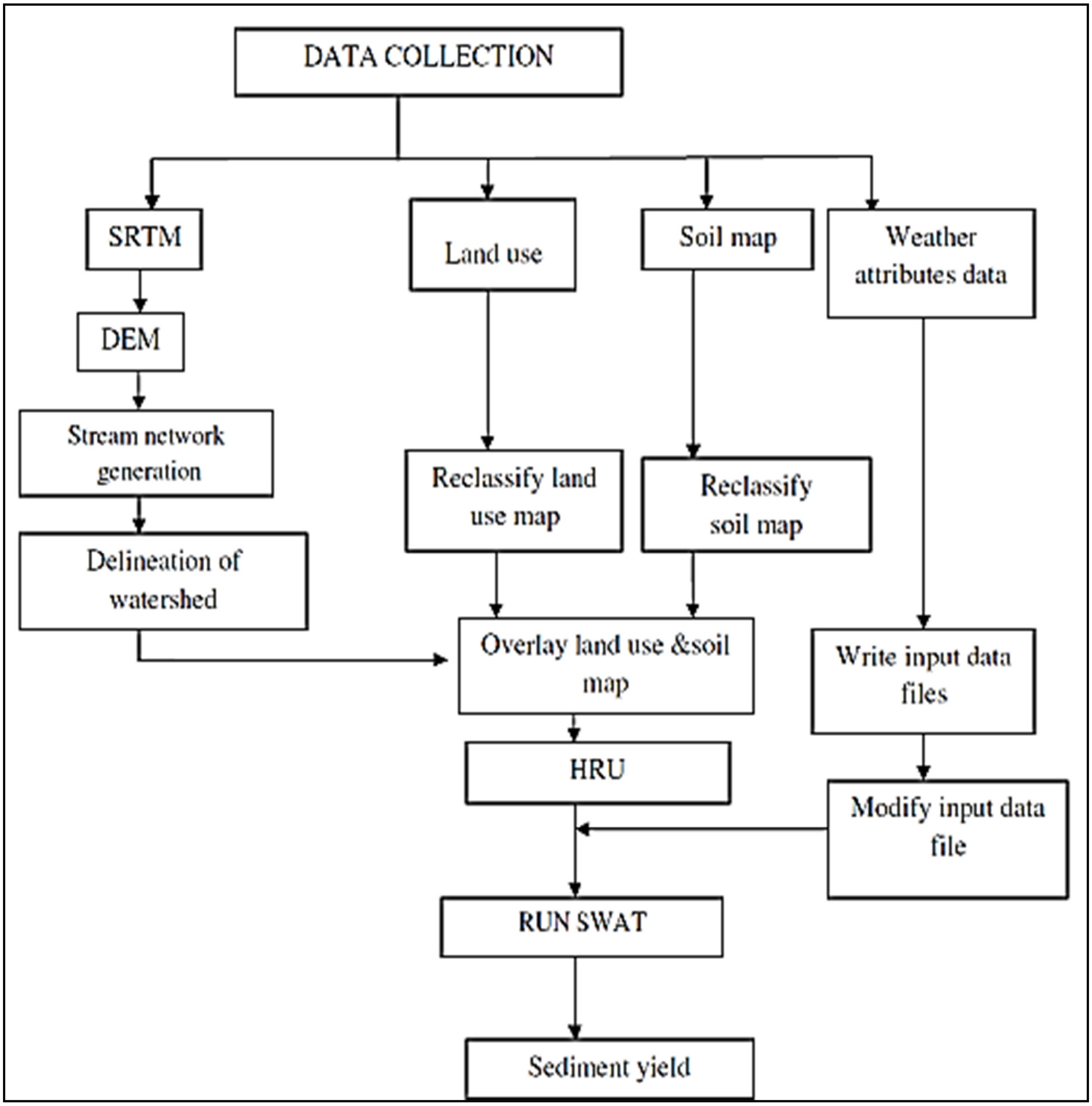


Figure 5-1: General algorithm used for sediment yield simulation in ArcSWAT

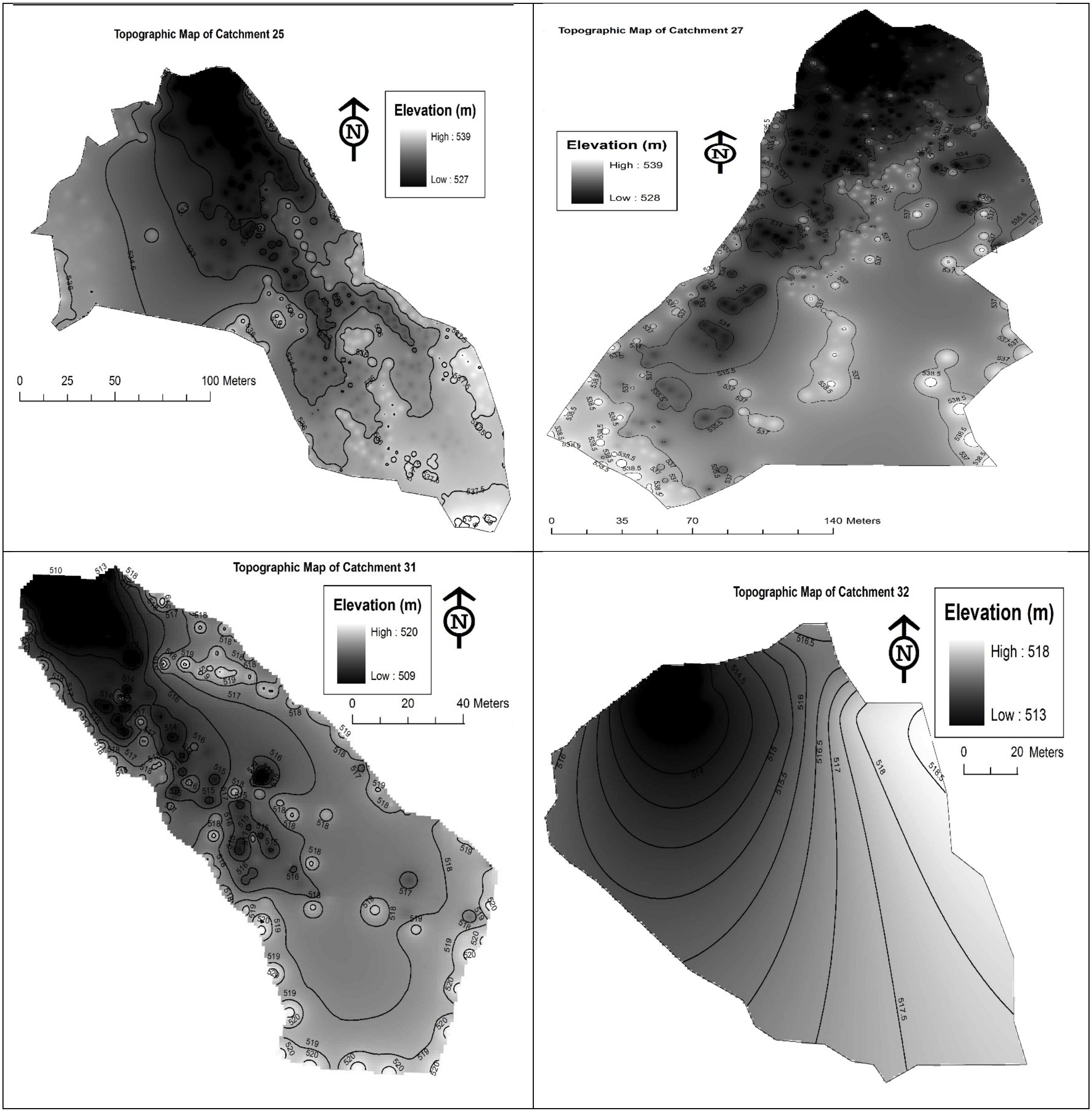


Figure 5-2: Topographic Maps of 25, 27, 31 and 32 Catchments

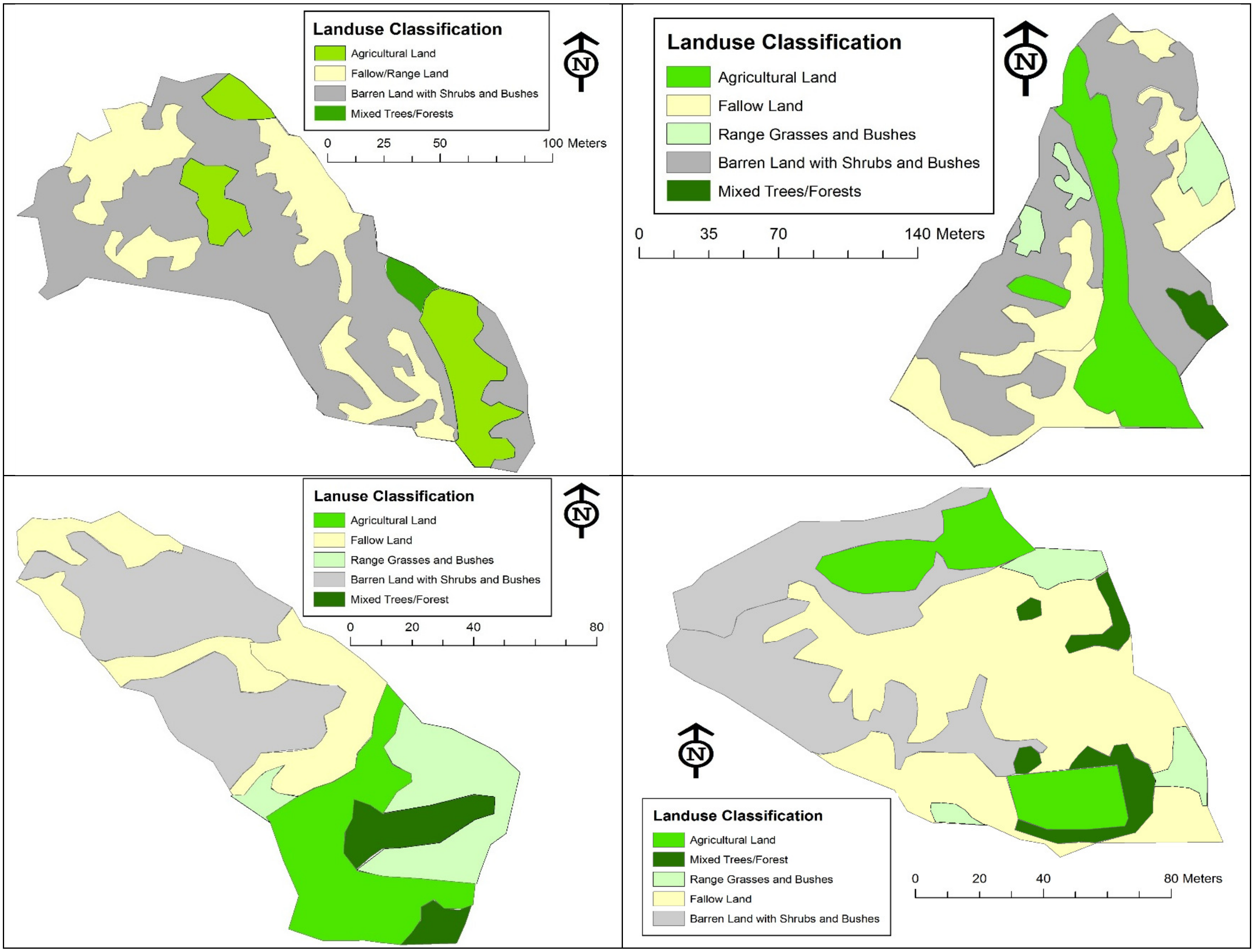


Figure 5-3: Landuse Maps of 25, 27, 31 and 32 Catchments

Table 5.2: Landuse classification of sub-catchments

Processed Landuse	SWAT Class	Percentage of Catchment Area			
		Cat-25	Cat-27	Cat-31	Cat-32
Agricultural Land	Agricultural Land Generic (AGRL)	**14.19**	**2.15**	**19.83**	**11.48**
Fallow Land	Crop Land/Grass land Mosaic (CRGR)	**24.54**	**25.26**	**23.42**	**45.68**
Mixed Trees/ Forest	Forest Mixed (FRST)	**1.49**	**1.75**	**7.66**	**5.04**
Range Grasses and Bushes	Range Grasses (RNGE)	**0.00**	**5.20**	**15.41**	**9.39**

Barren Land with Shrubs and Bushes	Mixed Grass Land/ Shrubs (MIGS)	**59.78**	**47.64**	**33.68**	**28.40**

6 Model Performance Evaluation

Calibration and validation results were evaluated by graphical and statistical criteria such as, correlation coefficient, Nash Sutcliffe Efficiency ($E_{N.S}$), and Coefficient of Determination (R^2),

6.1 Nash-Sutcliffe Coefficient [NS]

Nash-Sutcliffe coefficient measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data.

Nash-Sutcliffe efficiencies can range from 0 to 1. An efficiency of 1 corresponds to a perfect match of modelled discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (NS < 0) occurs when the observed mean is a better predictor than the model. Besides, due to frequent use of this coefficient, it is known that when values between 0.6 and 0.8 are generated, the model performs reasonably. A value between 0.8 and 0.9 tells that the model performs well and a value between 0.9 and 1 indicates that the model performs extremely well. The formula for Nash- Sutcliffe (NS) is:

$$\boldsymbol{E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{n}\sum(Q_{oi} - \bar{Q}_0)^2}}$$

where: E_{NS}: Nash-Sutcliffe coefficient, $\boldsymbol{Q_{oi}}$: Observed sediment flow, $\boldsymbol{Q_{si}}$: Simulated sediment flow and $\boldsymbol{\bar{Q}_0}$: Average of observed sediment flow.

6.2 Coefficient of Determination [R^2]

The coefficient of determination, denoted R^2, provides a measure of how well observed outcomes are replicated by the model. The range of R^2 lies between 0 and 1 which describes how much of the observed desperation is explained by the prediction. A value of zero means no correlation at all; whereas one means that the dispersion of the prediction is equal to that of the observation.

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_{si} - \overline{Q}_s)\ (Q_{oi} - \overline{Q}_o)]^2}{\sum_{i=1}^{n}(Q_{si} - \overline{Q}_s)^2 \sum_{i=1}^{n}(Q_{oi} - \overline{Q}_o)^2}$$

7 Results and Discussion

7.1 Model Calibration, Validation and Application

To maximize the model performance efficiency, calibration and validation of soil erosion parameters were done using manual calibration procedure (trial-and-error method) based on the literature references and calibration technique described in SWAT user manual. Calibration of the model is the setting or correcting output values of the model by changing values of input parameters in an attempt to match these with field conditions or observed values within some acceptable criteria and model validation is the process of performing model simulation with a different dataset from the calibration dataset, keeping the calibrated parameters constant, which is used to test whether the calibrated parameters were appropriate for the study basin. General procedure which was adopted for manual calibration of soil erosion parameters in manual calibration helper tool of Arc SWAT as given in figure 5.1

The calibration and validation was performed using observed data of sediment (ton/ha) for the year 2009 and 2010, respectively which was measured at plastic collecting tank i.e. the experimental setup of Soil and Water Conservation Research Institute (SAWCRI) Chakwal in each sub-catchments. The validated model was then used for application using sediment data of year 2011.

The time-series plots of measured and simulated data of each sub-catchment after calibration were drawn as given in Figs. 7.1, 7.2, 7.3 &7.4 and then two statistical indicators, Nash and Sutcliffe coefficient of efficiency ($E_{N.S}$) and coefficient of determination (R^2) were used to evaluate the performance of model for each sub-catchment as given in Table 7.1.

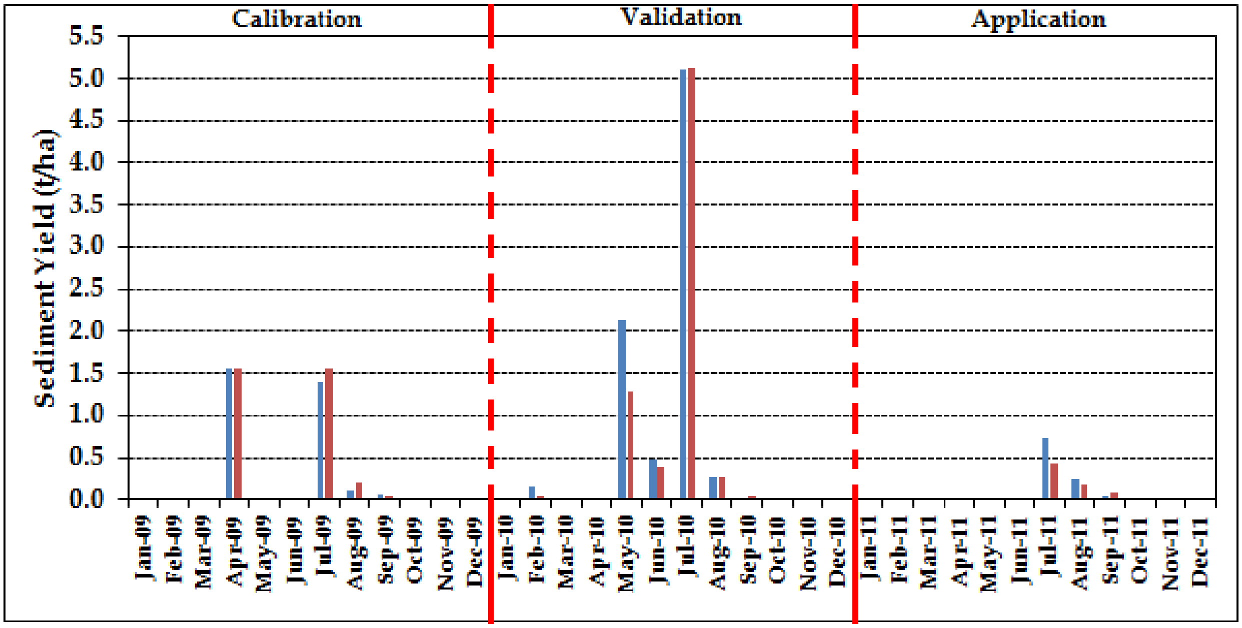


Figure 7.1: Model Calibration, validation and application for catchment 25

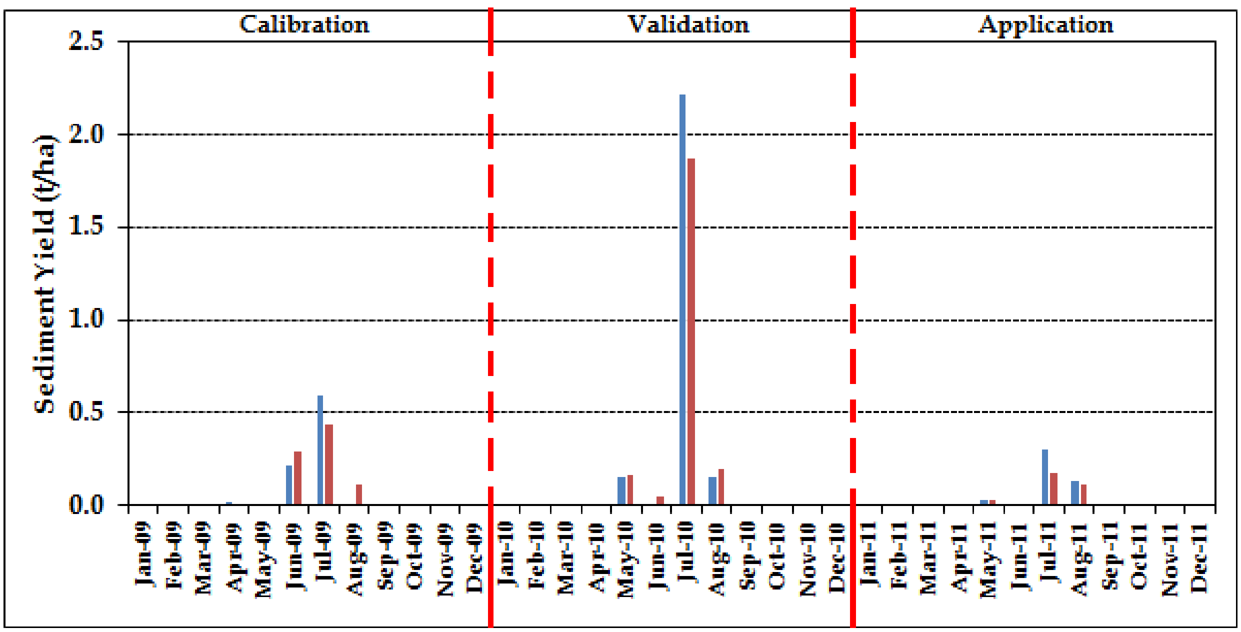


Figure 7.2: Model Calibration, validation and application for catchment 27

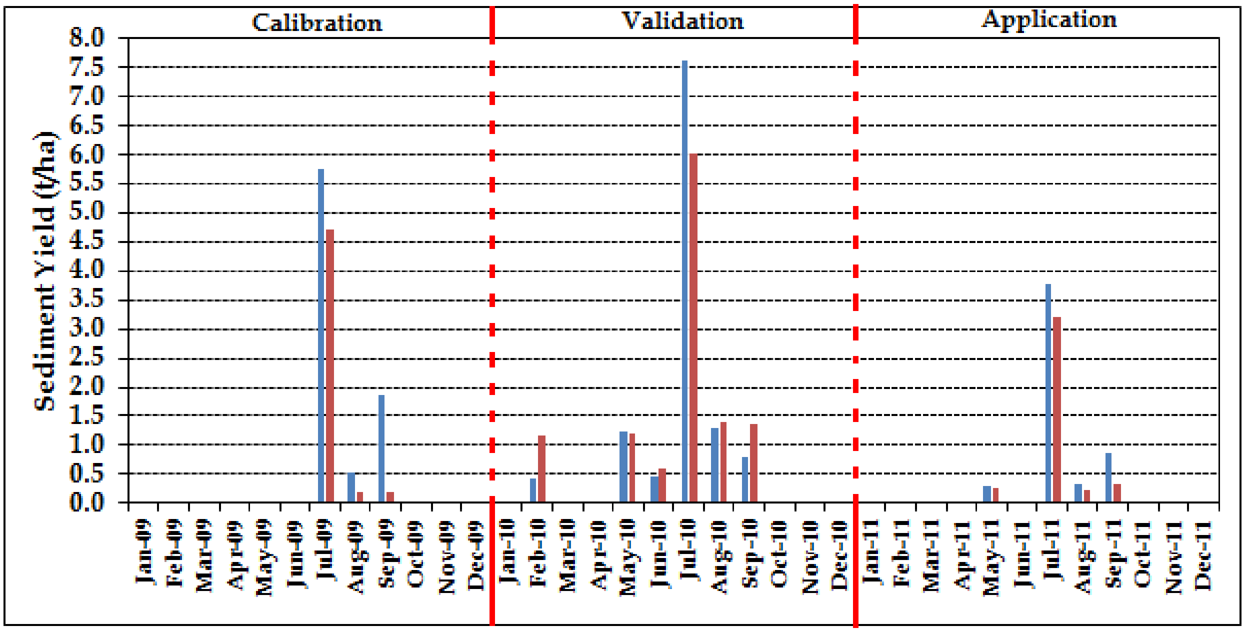


Figure 7.3: Model Calibration, validation and application for catchment 31

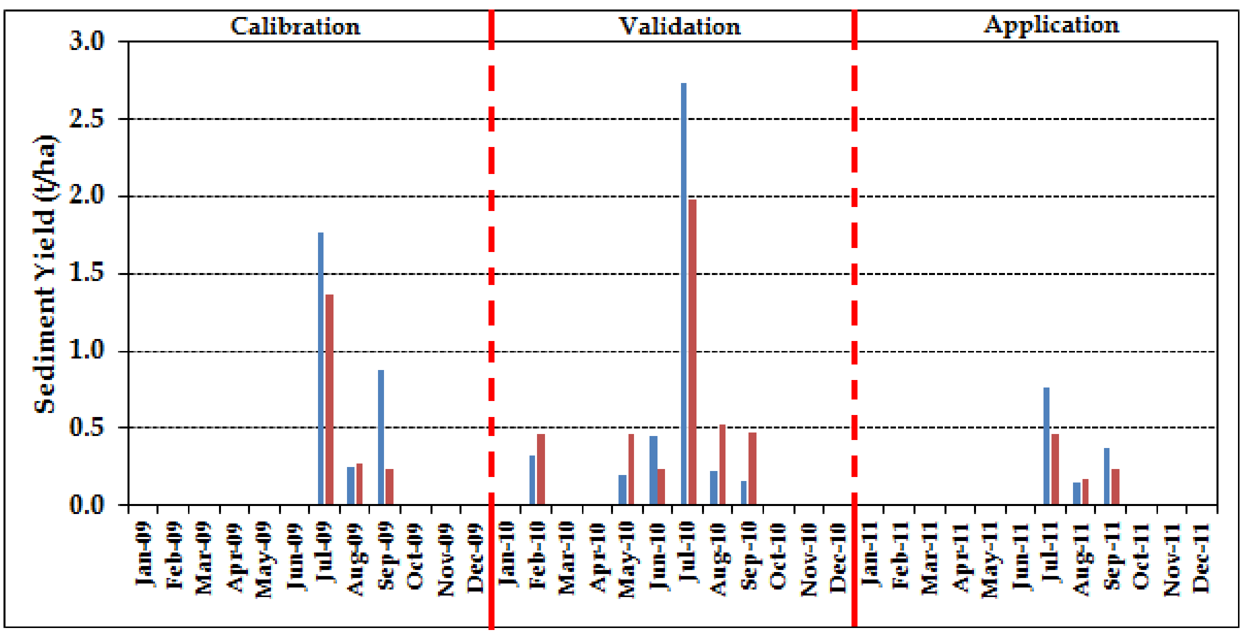


Figure 7.4: Model Calibration, validation and application for catchment 32

Comparison between observed and simulated sediment yield for all events in 2009 to 2011 are shown by graphical display for all four sub-catchments is shown in Fig.7.5

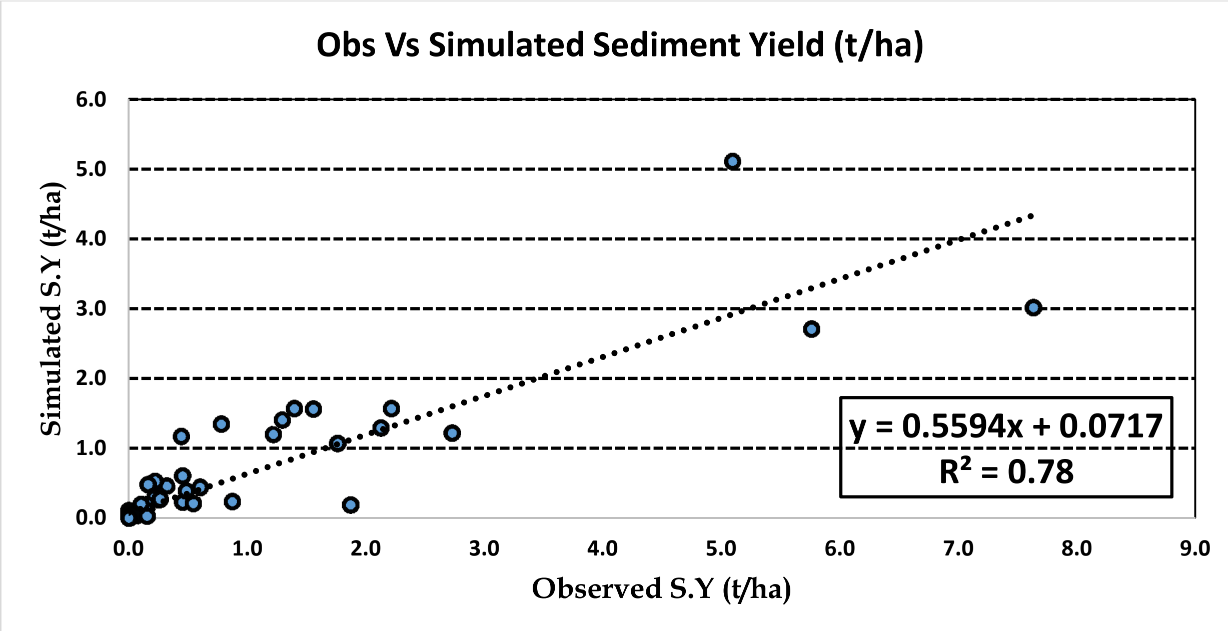


Figure 7.5: Observed and Simulated sediment yield comparison from 2009 to 2011

This revealed that there is a good relationship between measured and simulated sediment yield because the value of correlation coefficient is 0.78. The model performance coefficients values for calibrated and validated data are given below.

Table. 7.1

Table 7.1: Model Performance Evolution

Model Calibration				
Parameter	**Catchment 25**	**Catchment 27**	**Catchment 31**	**Catchment 32**
R^2	0.89	0.87	0.80	0.88
$E_{N.S}$	0.86	0.81	0.77	0.80
Model Validation				
R^2	0.83	0.86	0.83	0.87
$E_{N.S}$	0.76	0.71	0.79	0.86
Model Application				
R^2	0.79	0.78	0.74	0.76
$E_{N.S}$	0.74	0.72	0.78	0.87

8 Parameter Sensitivity Analysis

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output value with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000).

Sensitivity analysis was performed with one–factor-at-a-time (OAT) approach for sediment yield calibration using six parameters and list of parameter ranking was found in sensout.out file which is given in Table 8.1 with default and value used for sediment yield calibration.

Table 8.1: Sensitivity analysis of Soil erosion parameters

Parameter sensitivity ranking	**Default range**	**Value used**			
		Cat-25	**Cat-27**	**Cat-31**	**Cat-32**
USLE_P	0 to 1	0.11	0.89	0.13	0.32
SPEXP	1.0 to 2.0	1.0	1.33	1.099	1.13
SPCON	0.0001 to 0.01	0.0032	0.0032	0.006	0.007
USLE_C	0.001 to 0.5	0.182	0.164	0.179	0.192
USLE_K	0 to 0.65	0.246	0.211	0.2537	0.252

In this research study, ArcSWAT, a process based partially distributed hydrological model having an interface with ArcGIS software was used for modelling sediment yield for Dhrabi watershed in Chakwal. Four sub-catchments of similar characteristics of Dhrabi watershed were selected.

After preparing all required thematic maps and database as per the format of Arc SWAT model for all sub-catchments, model was setup and calibrated for monthly sediment yield using the observed data of 2009 to 2010 separately for each catchment named as Cat-25, Cat-27, Cat-31 and Cat-32. The model validation was carried out for a dataset of year 2011. The performance of the model for calibration and validation was evaluated using graphical and statistical methods. For the calibration and validation period, in graphical approach the correlation coefficient between observed and simulated data was 0.78 for combined sub-catchments. The values of coefficient of determination R^2 and NS coefficient for the sediment yield using manual calibration approach for calibration and validation period was given in above table. The model performance evaluation coefficients shown in this study can be considered reasonably satisfactory and the SWAT model is capable of predicting sediment yields for Dhrabi watershed with limited data availability.

The statistical results of the model's performance in sediment yield prediction during calibration and validation periods with sensitivity analysis showed that the high E_{NS} and R^2 values above 0.7 and 0.8 respectively for calibration of four sub-catchments and for validation period E_{NS} and R^2 values were above 0.65 and 0.65 indicate that the model preformed fairly well for sediment yield during calibration and validation periods and the results were satisfactory.

10 Model Application to Conservation Structures

After model calibration, validation and sensitivity analysis of different parameters, the model was applied to watershed where stones structures were previously constructed to check the soil erosion. The following sites were modeled:

1. Kohkar Bala
2. Khandoa
3. Dhoke Mori (Khaliq Gulli, Ashraf Gulli)
4. Chak Khushi
5. Dhok Dhamal
6. Dhok Hafiz Abad

The sites 1 to 4 are located in District Chakwal, whereas site 5 and 6 are situated in District Attock. The model was applied to six years of data from Jan 2010-April 2015. The topographic survey of the selected sites was conducted to mark the flow contributing area for different structures as shown in Figs. 10.1, 10.2 &10.3. The daily rainfall data was collected from meteorological station at SWACRI office in Chakwal.

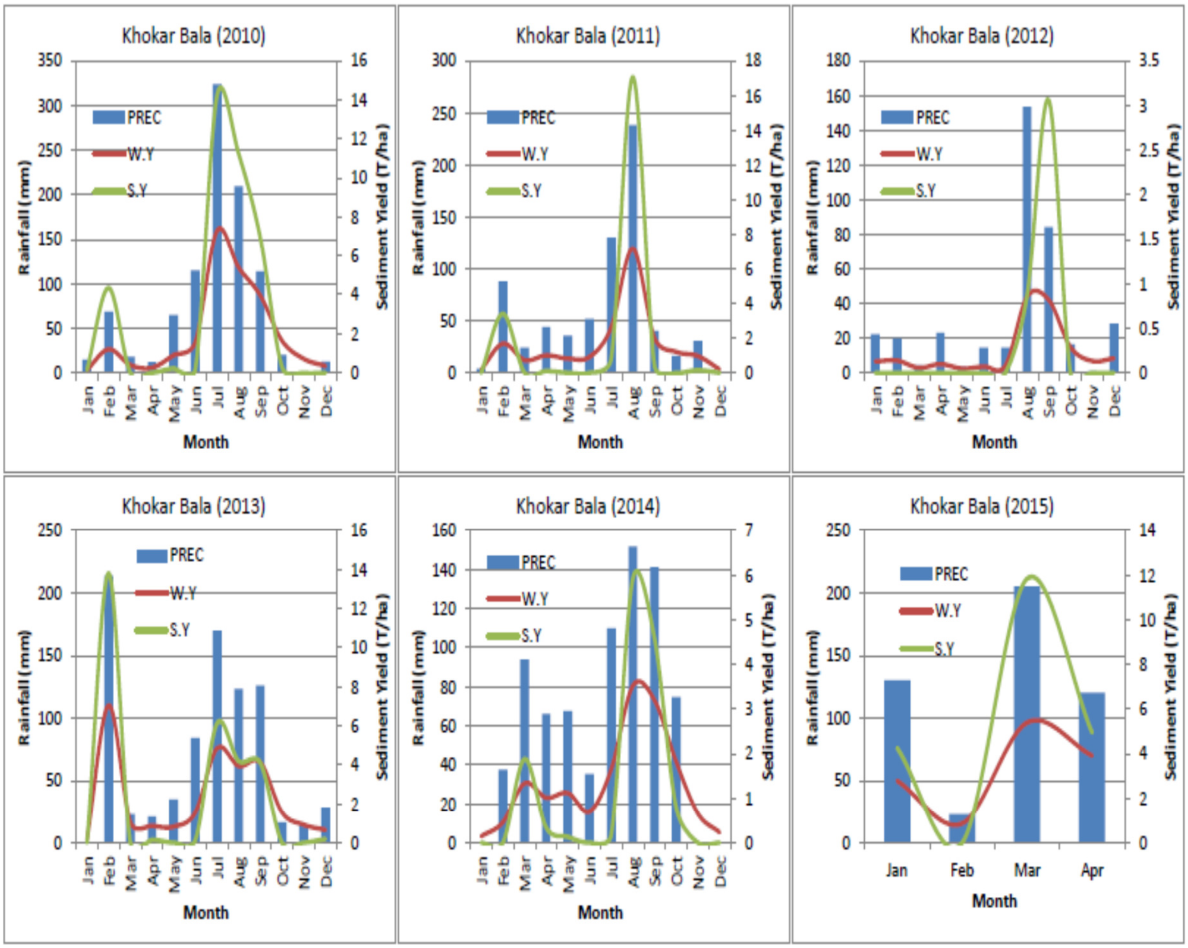
Figure 10-1: Data Collection from Dhoke Syedan and Dhamal site at Fatehjang

Figure 10-2: Data Collection using GPS at Dhoke Hafizabad

Figure 10-3: GPS data collection at different site of Chakwal District

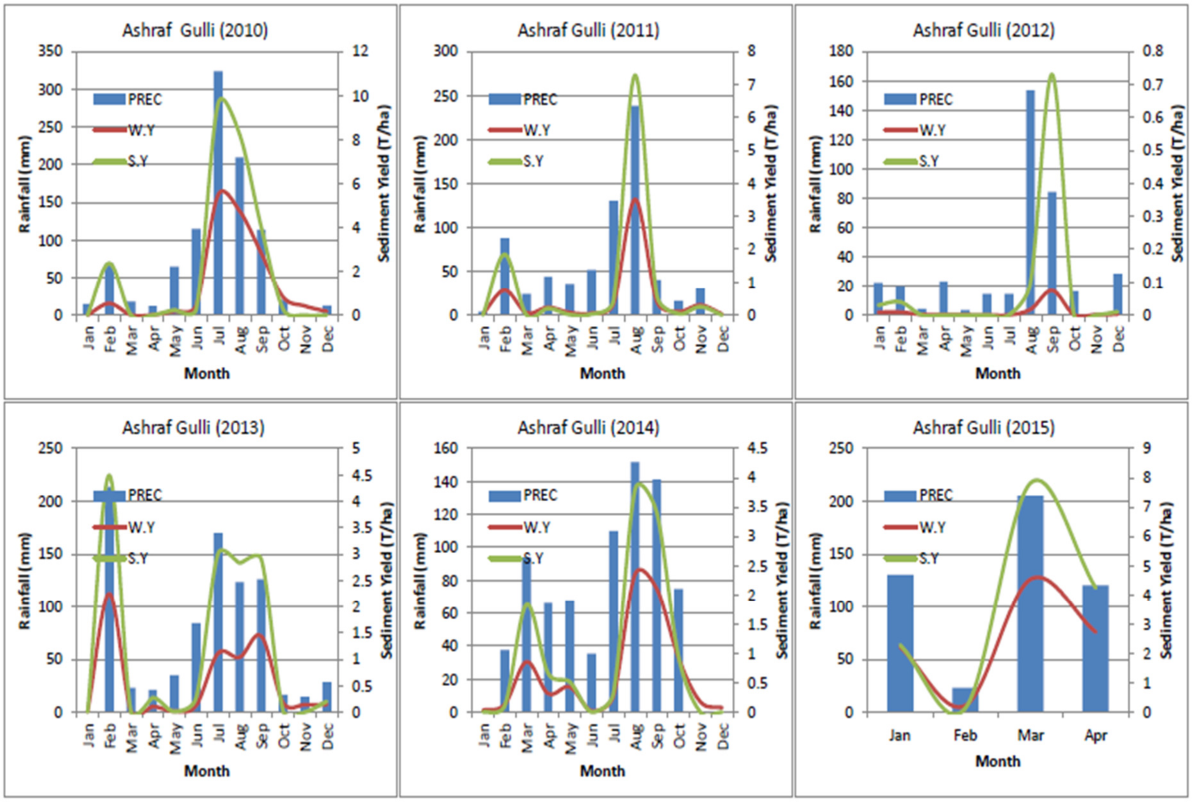
11 Soil Erosion Estimation

After preparation of requisite data file for SWAT model input, the model was run for all the selected sites for six years from Jan 2010 to April, 2015. The results of different sites are shown in following Figs.12.1 to 12.7



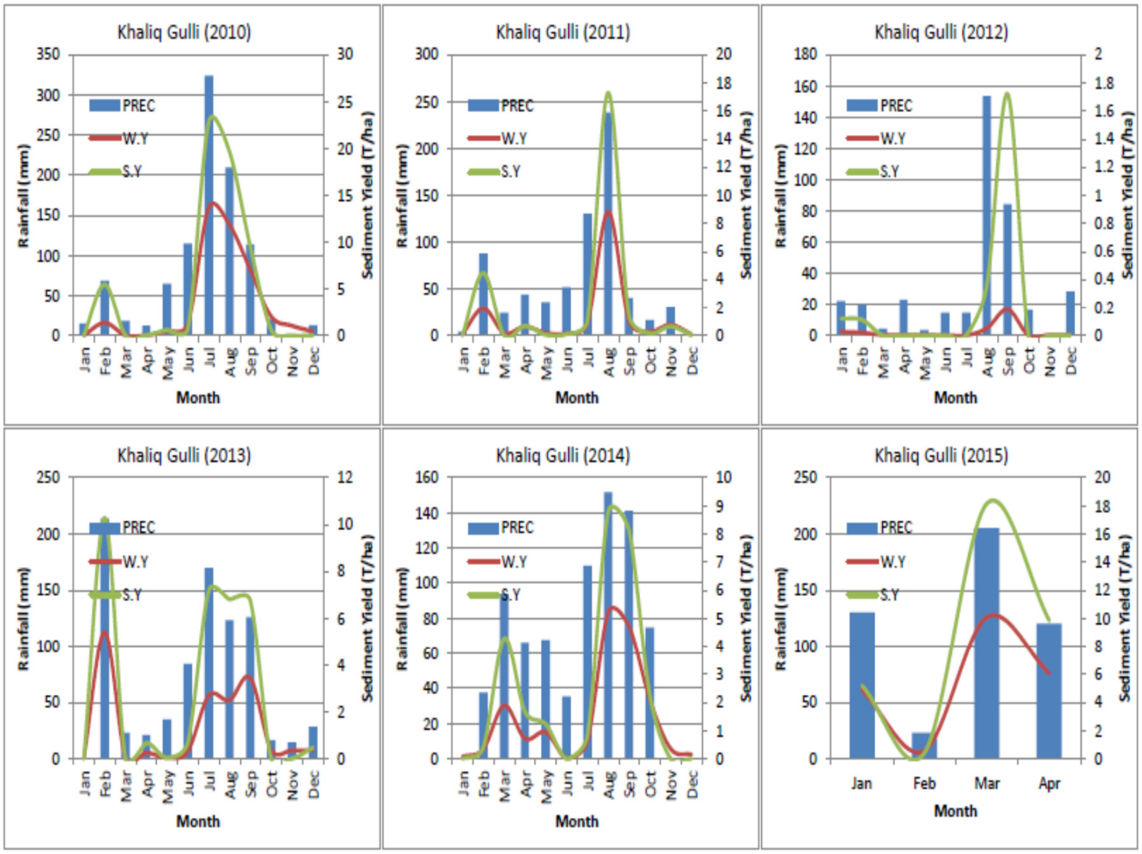
Soil Erosion simulated using SWAT model for Khokar bala site

Figure 11-1: Soil Erosion Estimation at Khokar Bala Site



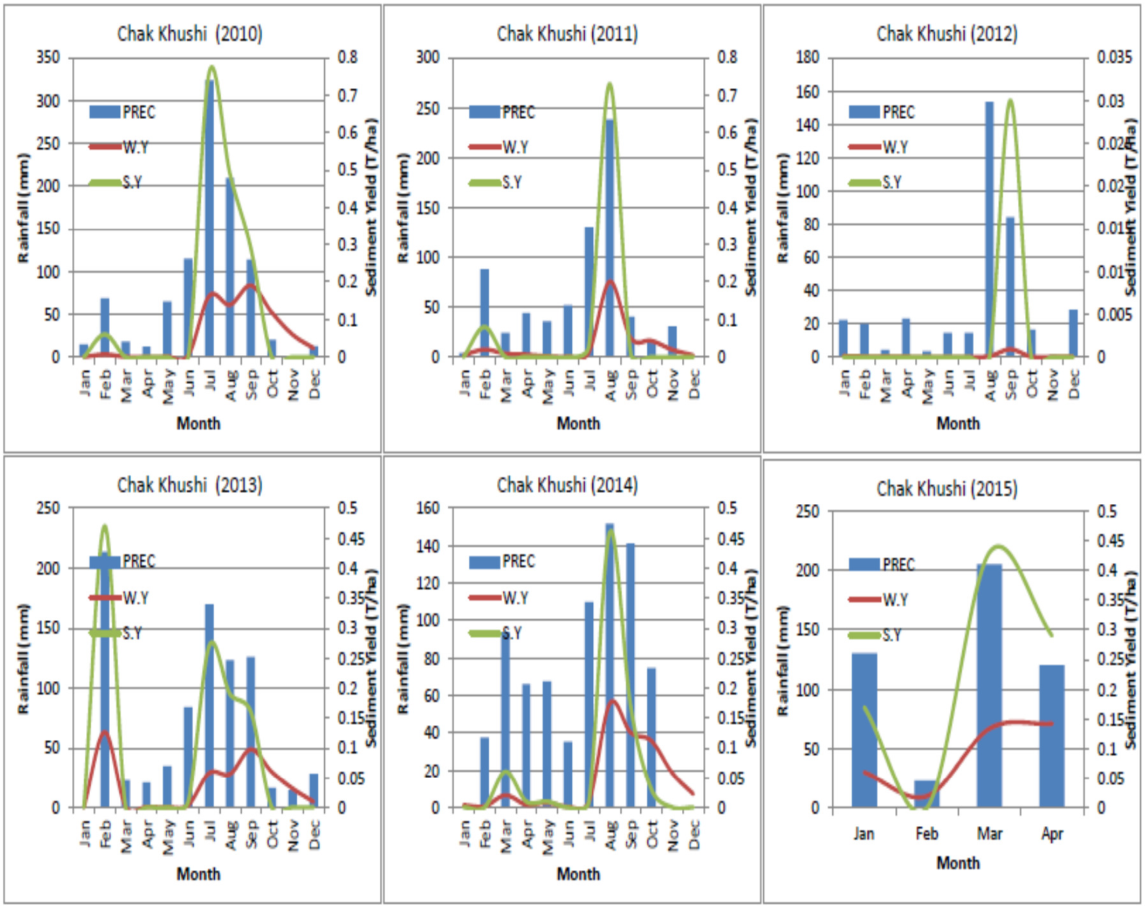
Soil Erosion simulated using SWAT model Ashraf Gulli Dhok Mohri site

Figure 11-2: Soil Erosion Estimation at Ashraf Gully Site



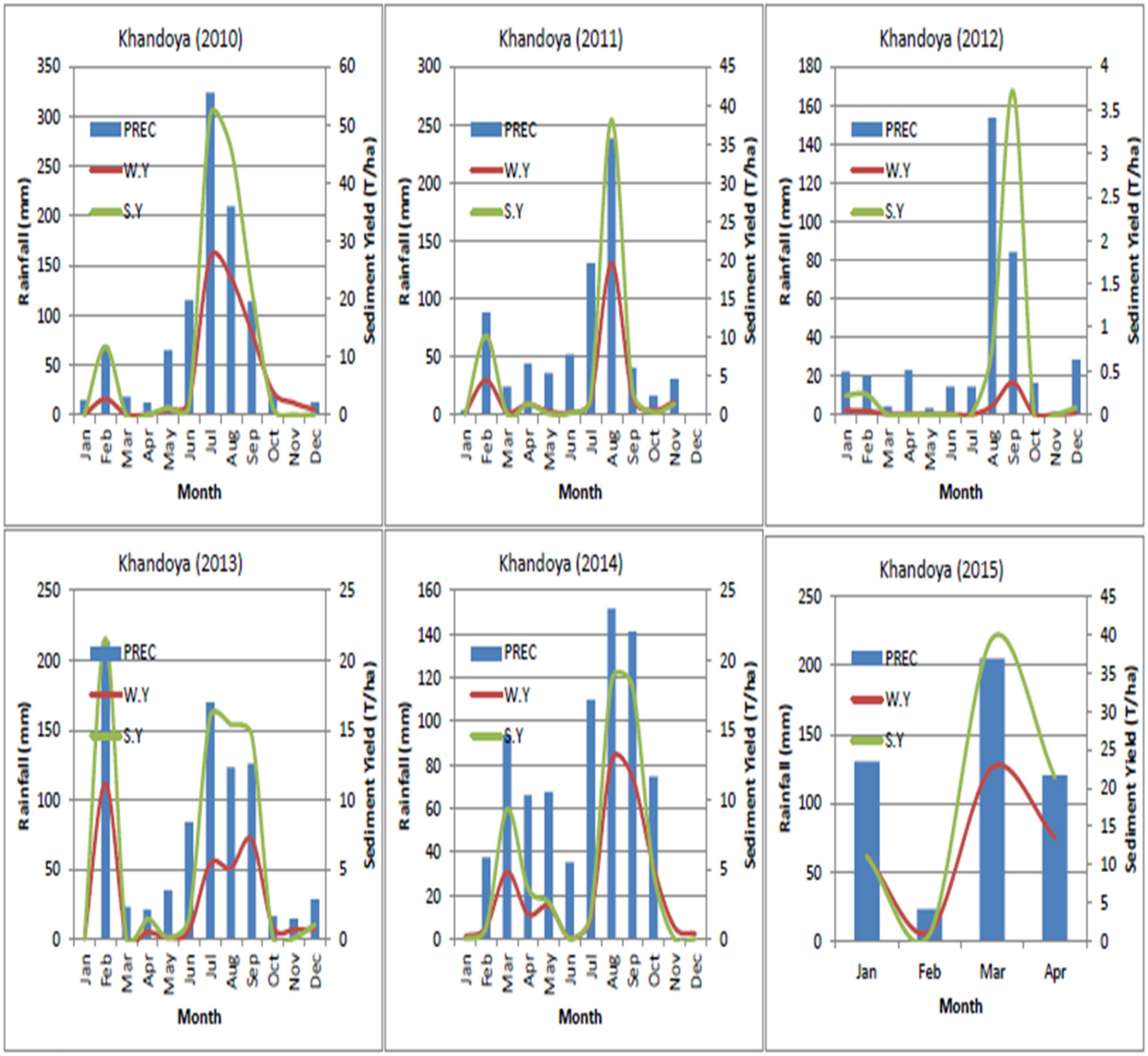
Soil Erosion simulated using SWAT model Khaliq Gulli Dhok Mohri site

Figure 11-3: Soil Erosion Estimation at Khaliq Gully Site



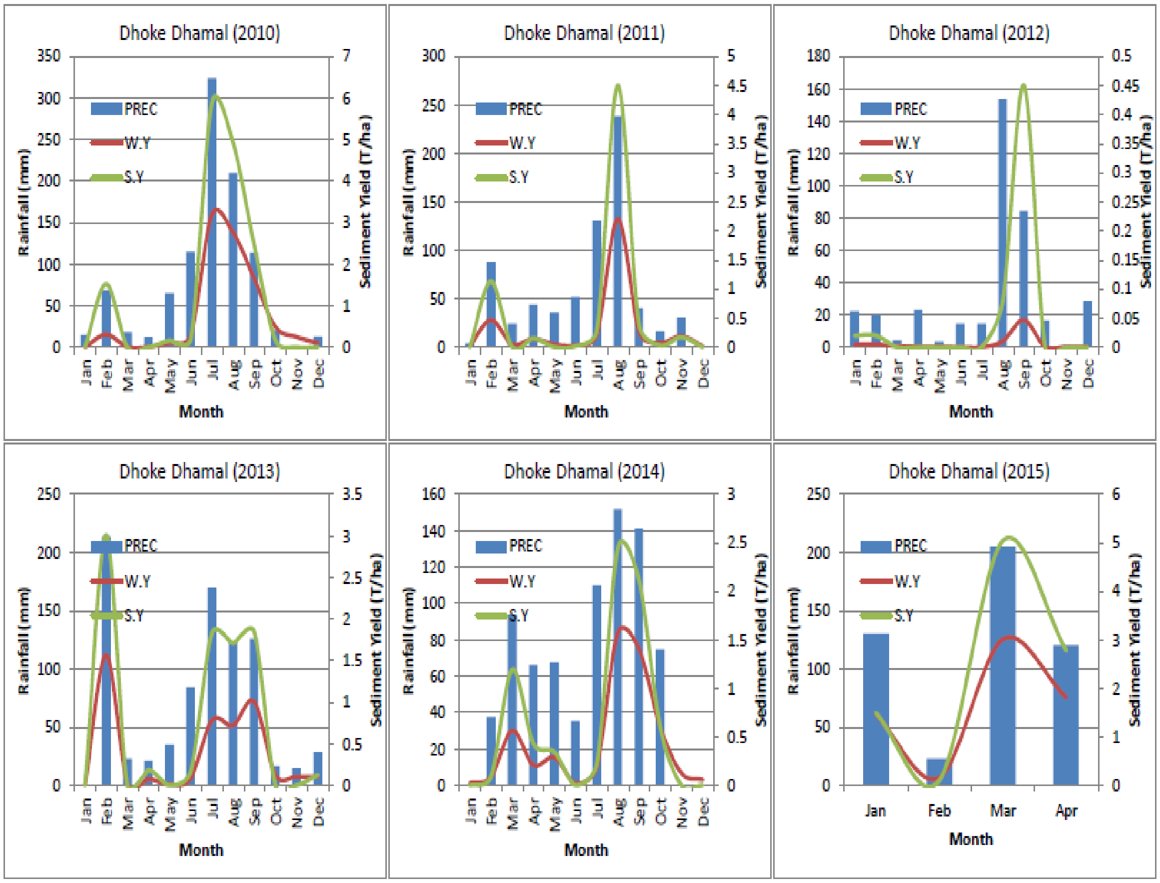
Soil Erosion simulated using SWAT model Chak Khushi site

Figure 11-4: Soil Erosion Estimation at Chak Khushi Site



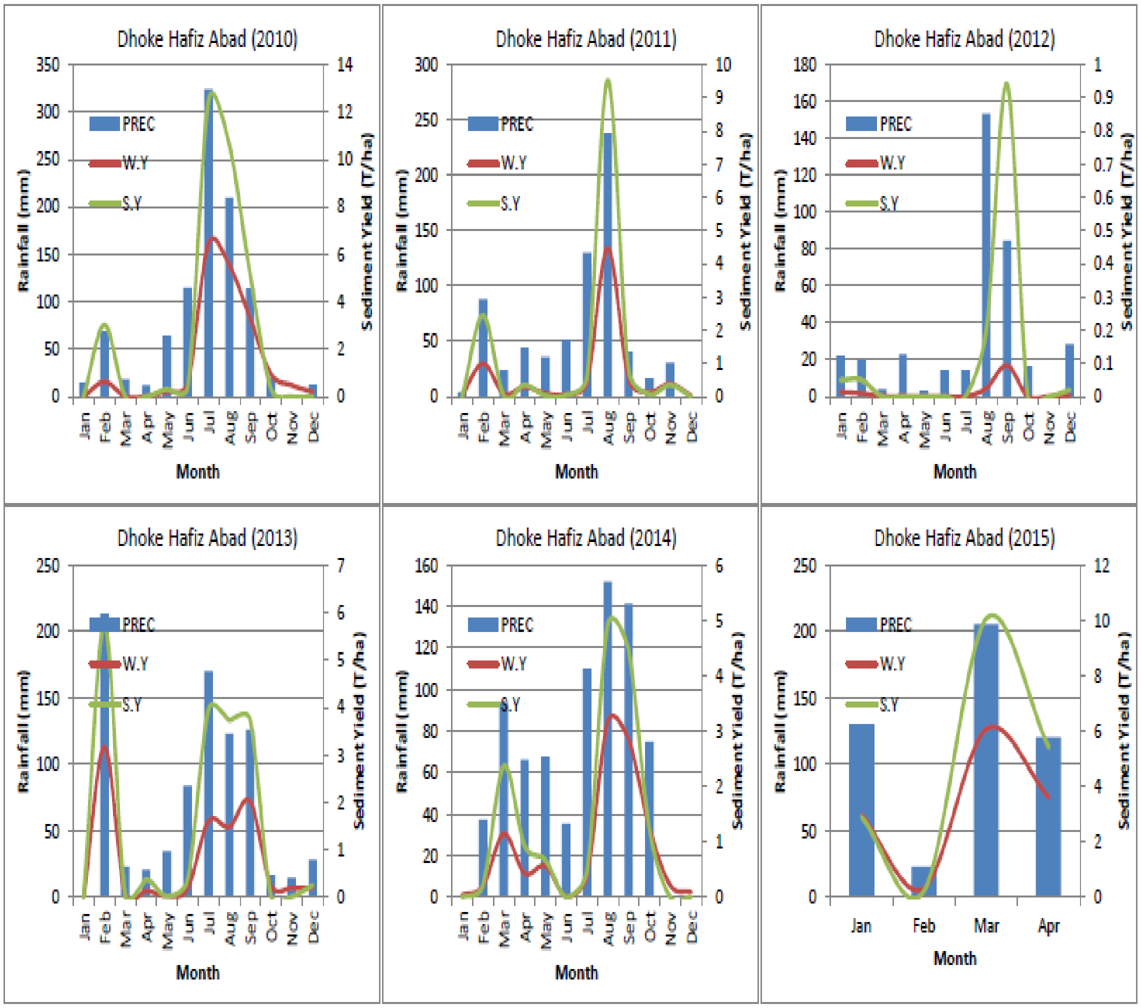
Soil Erosion simulated using SWAT model Khandoya site

Figure 11-5: Soil Erosion Estimation at Khandoya Site



Soil Erosion simulated using SWAT model Dhok Dhamal Fathe Jhang site

Figure 11-6: Soil Erosion Estimation at Dhoke Dhamal Site



Soil Erosion simulated using SWAT model Dhok Hafiz Abad Fathe Jhang site

Figure 11-7: Soil Erosion Estimation at Dhoke Hafiz Abad Site

12 Effects of Conservation Structures on Sediment Yield

Structure Type: All the structures were loose stone apron type without steel wire meshing. The geometry of all the structures was similar to weir type spillway. The crest of structure played a major role in reduction of the flow velocity that create ponding and results in sediment deposition (erosion reduction) upstream the structure while the downstream section downstream section of structure prevent the channel or gully development. The snap shot of structure at different location is shown in Fig. 13.1

Figure 13.1 view of loose stone structures

The SWAT model uses Modified Universal Soil Loss (MUSLE) to compute soil erosion. The soil erosion due to water yield is calculated at delineated Hydrologic Response Units (HRU). The sediment detachment and transported is based on hydraulic energy die to surface runoff (William & Berndt, 1977). The routing and degradation in channels is done by stream power approach (William, 1980). The stream power is defined as product of shear stress and flow velocity (ƮU), where Ʈ is shear stress and U is flow velocity. The sediment deposition is estimated based on the fall velocity of sediment particles.

The SWAT model estimates the transport capacity of a channel segment as a function of the peak channel velocity, Tch = avb   where Tch (ton/m3) is the maximum concentration of sediment that can be transported by streamflow (transport capacity), a and b are user defined coefficients, and v (m/s) is the peak channel velocity. The peak velocity in a reach segment is calculated as

$$v = \frac{\alpha}{n} R_{ch}{}^{2/3} S_{ch}{}^{1/2}$$

where a is the peak rate adjustment factor with a default value of unity, n is Manning's coefficient, Rch is the hydraulic radius (m), and Sch is the channel invert slope (m/m). Channel degradation (Seddeg) and deposition (Seddep) in tons are computed as:

$$sed_i > T_{ch} \ : \ sed_{dep} = (sed_i - T_{ch}) \times V_{ch}$$
$$\& \ sed_{deg} = 0$$

$$sed_i < T_{ch} \ : \ sed_{deg} = (T_{ch} - sed_i) \times V_{ch} \times K_{ch} \times C_{ch}$$
$$\& \ sed_{dep} = 0$$

Where: sedi is the initial sediment concentration in the channel segment (ton/m3), Vch is the volume of water in the channel segment (m3), Kch is the channel erodibility factor

(cm/hr/Pa), and Cch is the channel cover factor. The total amount of sediment that is transported out of the channel segment (sedout) in tons is computed
as:

$$sed_{out} = \left(sed_i + sed_{\deg} - sed_{dep}\right) \times \frac{V_{out}}{V_{ch}}$$

Vout is the volume of water leaving the channel segment (m3) at each time step.

The parameter representing the stone strictures include averaged slope length (SLSUBBSN), land management practice parameter P (USLE_P) Curve Number (CN2) for rainfall runoff conversion.
SLSUBBSN is changed in HRU input file *.hru, CN2 and USLE_P are changed in management input file *.mgt. The sensitive parameters for soil erosion in soil erosion estimation is USLE Land cover (USLE_C), Management Support factor (USLE_P), linear re-entrainment parameter for channel sediment routing (SPCON), exponent of re-entrainment parameter for channel sediment routing (SPEXP), channel cover factor (Ch_Cov), channel erodibility factor (Ch_Erod) and sediment routing in main channel (PSP). The stone structure reduce the soil erosion reported by (Herweg and LAudi, 1999, Gebremicheal rt.al., 2005). Herweg and Ludi (1999) reported 72% to 100% sediment yield reduction due to stone bund at plot scale, whereas Gebremichal et.al., 2005 reported 65% decrease in soil erosion at filed scale in northern part of Ethiopia.
The above mentioned approach was used to estimate the effectiveness of stone structures in sediment yield reduction.

The Parameter values used in model for effectiveness of stone structure are as reported by Betrie et al., 2011:

SLSUBBSN	60
HRU_SLP	0.016
CN2	65
USLE_P	0.65
SPCON	0.001
SPEXP	1.25

The effect of stone structures in reduction is shown in Table 13.1

Table 13.1 Sediment yield with and without structure at different sites.

Sediment Yield Rduction Due to Stone Structures															
	Khaliq Gully			Ashraf Gully			Khokar Bala			Dhok Dhmal			Chak Khushi		
Year	W.O Stru	With Stru	Reduc(%)	W.O Stru	With Stru	Reduc(%)	W.O Stru	With Stru	Reduc(%)	W.O Stru	With Stru	Reduc(%)	W.O Stru	With Stru	Reduc(%)
2010	59.3	30.3	49.0	25.0	10.4	58.5	37.6	0.9	97.6	15.3	8.3	45.7	1.6	0.8	49.4
2011	25.8	15.3	40.6	10.7	2.6	75.8	21.9	0.4	98.1	6.7	2.3	66.3	0.9	0.4	58.8
2012	2.3	0.0	100.0	0.9	0.0	100.0	3.9	0.1	98.5	0.6	0.0	98.2	0.0	0.0	100.0
2013	32.9	14.6	55.7	14.0	3.5	75.2	28.7	0.7	97.7	8.9	2.2	75.0	1.1	0.2	78.2
2014	27.6	11.9	57.0	11.6	2.2	81.1	13.8	0.2	98.6	7.4	1.8	75.4	0.8	0.2	69.7
2015	34.0	25.2	25.9	14.5	3.0	79.0	21.1	0.3	98.8	9.4	0.9	90.3	0.9	0.1	92.1
Average			54.7			78.3			98.2			75.2			74.7

Table 13.1 show the significant reduction in sediment yield incorporating the parameter values recommended for stone structure by Betrie et al. (2011). The sediment yield reduction varies from 40 to 90% for the different sites. The Khokar bala site shows the maximum reduction in sediment yield due to conservation structures. Table 13.1 shows that average five year sediment reduction due structure at various sites varies from 54 to 98%, same has been reported by Betrie et. al. (2011). Studies conducted by different professional and as reported in Awas and Ashraf (2012) that *"On average a water height of between approximately 10 cm and 15 cm can be held back in the fields. It was assumed that by using the stone spillways a heavy rainstorm of 100 mm would be retained on the terrace and would not overboard. Such rainstorms can occur during the monsoon. The water should infiltrate within 6 hours, which leads to an infiltration rate of 16.7 mm/hour or 4 m/day"*. For effectiveness of soil conservation structure (stone Structures) installed in Dhrabi watershed Chakwal at different locations it was calculated that in year 2009 average soil loss with and without structure was 37.98 and 47 T/ha/y with a 20% reduction. Whereas maximum soil loss with and without structure was 1731 and 2716.17 T/ha/y with a 37% reduction. Similarly, a 31% reduction in average soil loss and 36% reduction in maximum soil erosion were reported for year 2010 for the same catchment. Further, in same study it was reported that 22% of the Dhrabi watershed has soil loss 50 T/ha/y, and 40% area has soil erosion 153 T/ha/y. under different landuse.

Nabi et al. (2008) reported that in Soan Basin in Pothwar region, soil loss from barren and shrubs land is 63.41 T/ha/y and 53.41 T/ha/y whereas low cultivation and high cultivation land has soil loss 34.91 T/ha/y and 25.89 T/ha/y, respectively.

13.1 Different Scenarios Development

Apart from the effectiveness of the soil conservation structures as mentioned in Table 13.1, different scenarios were developed to estimate the further reduction in soil erosion with different type of landuse changes in the catchment areas of structures.

The SWAT model was applied based on four different scenarios on the Dhoke Mori (Khaliq and Ashraf Gulli) Catchments and Khandoya catchment. The scenarios description is given below.

S1 Scenario: Model was applied for soil erosion estimation without structures under the conditions i.e. the landuse type is winter wheat and for over land flow, (manning's n = 0.15, for short grasses), for channel flow (manning's n = 0.025, natural, earth uniform stream).

S2 Scenario: The model was applied with structure under the same conditions of S1 scenario.

S3 Scenario: In this scenario the landuse type was fallow land, without structure effect and manning's n for overland flow is 0.09 for fallow land with crop residue and channel flow conditions remain same.

S4 Scenario: this scenario gave the effect of model application with structure under the same conditions of S3 scenario.

Using these scenarios, the model was applied separately for all catchments and the results were obtained with and without conservation structure as shown below.

13.2 Effect of Conservation Structures

The analysis of different scenarios shows that, the sediment yield is more under scenarios S1 and S2 as compared to scenarios S3 and S4 which indicate that under agricultural land the sediment yield is more than fallow land with crop residue. The comparative analysis of S1 and S2 shows that, the average sediment yield reduction (1.25 t/ha) by the application of conservation structure under winter wheat agricultural land use while on the other hand in fallow land with crop residue, S3 and S4 scenarios analysis indicates that, the average sediment yield reduces up to 0.85 t/ha, as shown in Table 13.2.

Note: By visual observation of different structures in the study area it was noted that generally the effect of structure in soil erosion control extends up to 4 to 5 meter radius from the center of the crest of structure. In high flow seasons the water accumulate and sediment is deposited upstream of the structures.

Table 12.2: Effect of Soil Conservation Structure

Catchment	S1 (t/ha)	S2 (t/ha)	Sediment yield reduction	S3 (t/ha)	S4 (t/ha)	Sediment yield reduction
Ashraf Gulli	10.95	10.15	0.80 t/ha	7.91	7.04	0.86 t/ha
Khaliq Gulli	25.98	24.75	1.23 t/ha	17.10	16.5	0.60 t/ha
Khandoya	48.75	47.0	1.75 t/ha	42.28	41.18	1.1 t/ha

As shown in Table 13.2 the maximum sediment yield reduction is 0.85t/ha, because the area of the selected catchments are very small (less than hectare). This reveals that landuse change can also help in sediment yield reduction along with soil conservation structures.

13.3 Model Upscaling for District Attock and Rawalpindi

As mentioned above, soil loss within different landuse has been well reported by different researchers. The land slope is also a significant parameter responsible for soil erosion. The shear stress (force per unit area) due to flow water is basic criteria for assessment of erosion of soil particle due to overland flow. The shear stress is directly proportional to land slope. It means steeper land slope, greater will be shear stress and consequently soil erosion potential will be more.

Further when soil conservation structures are installed in the field the farmer's concentration is to cultivate the area above and below the structure. The land uses in catchment of all the structures at different location were agriculture crop cultivations. Keeping in view the above factor it was decided to estimate the potential area to be benefited by the installed of structure. The area under different slope at different locations under study is shown in Table 13.3

Table 13.3 Percent area under different slopes at different locations in the study area

Ashraf Gully		Khaliq Gully		Khokar Bala		Dhok Dhamal		Chak Khushi	
Slope (%)	Area (%)	Slope (%)	Area (%)	Slope (%)	Area (%)	Slope (%)	Area (%)	Slope (%)	Area (%)
0-2	63	0-2	50	0-5	10	0-2	81	0-2	97
"2-5"	30	"2-5"	8	"5-10"	25	"2-5"	17	"2-5"	3
5-above	7	5-above	42	10-above	65	5-above	1		

Table 13.3 shows that the major area of the selected watershed falls under the soil slope ranges 0-4% and 4-8%. The agriculture practices are only possible on soil having slope less than 8%, otherwise the land grading has to be carried out. The same has been recommended by different authors; even Universal Soil Loss Equation (USLE) experiment carried at SAWCRI office concluded that only less than 10% slope is acceptable for agriculture practices under rainfed conditions.

The average sediment yield reduction during five year simulation at different location shows that sediment yield reduction varies from 0.7 t/ha/y to 19.4 t/ha/y as shown in Table 13.4

Location	Avg. Sediment Yield (t/h/y)		
	WO St	W St	Yield Red
Khaliq Gully	36.4	16.93	19.47
Ashraf Gully	15.3	10.99	4.31
Khokar Bala	25.4	24.96	0.44
Dhok Dhmal	9.6	6.5	3.1
Chak Khushi	1.1	0.7	0.4

The table 13.4 shows that higher is the sediment yield without structure more is sediment yield reduction. This shows that structures performance is proportionally with soil erosion.

13.3.1 Area under Different Slopes in District Attock

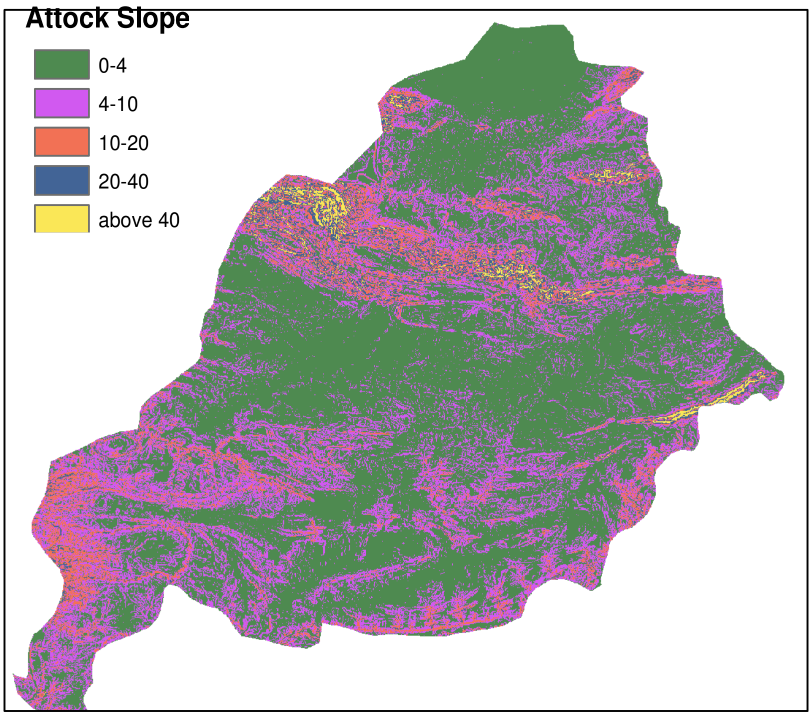
The 90 m SRTM Digital Elevation Model DEM of Attock district was analyzed for different slopes ranges. The area under different slopes was also calculated as shown in

Table 13.5

Chakwal			Attock		
Slope (%)	Area (KM2)	Area(%)	Slope (%)	Area (KM2)	Area(%)
0-4	4095	60	0-4	3918	61
4-10.1	1913	28	4-10.1	1786	28
10.1-20	547	8	10.1-20	472	7
20.1-40	233	3	20.1-40	165	3
40-90	75	1	40-90	55	1

The Table 13.5 shows that maximum areas in district Attock (94%) and Chakwal (94.5%) lies in slope less than 20%. The table 13.3 also present that all the catchment of selected sites has maximum area less than 5%, because the selected sites were used for agriculture production, the farmers have graded the land suitable for crop production and generating less surface runoff.

The pie chart (Figure 13.1) shows that about 61% (3918 km^2) area of District Attock lies in slope range 0-4%, whereas 28% (1786 km^2) area lies in slope range of 4-10%. It is concluded that there is huge potential for soil conservation adoption in District Attock. The Betrie et. al., 2011 in their study in Nile river basin recommended that stone bund option for soil conservation should be applied at low slope area. However the effectiveness of structures depends on the local topography and soil and land use land cover conditions.



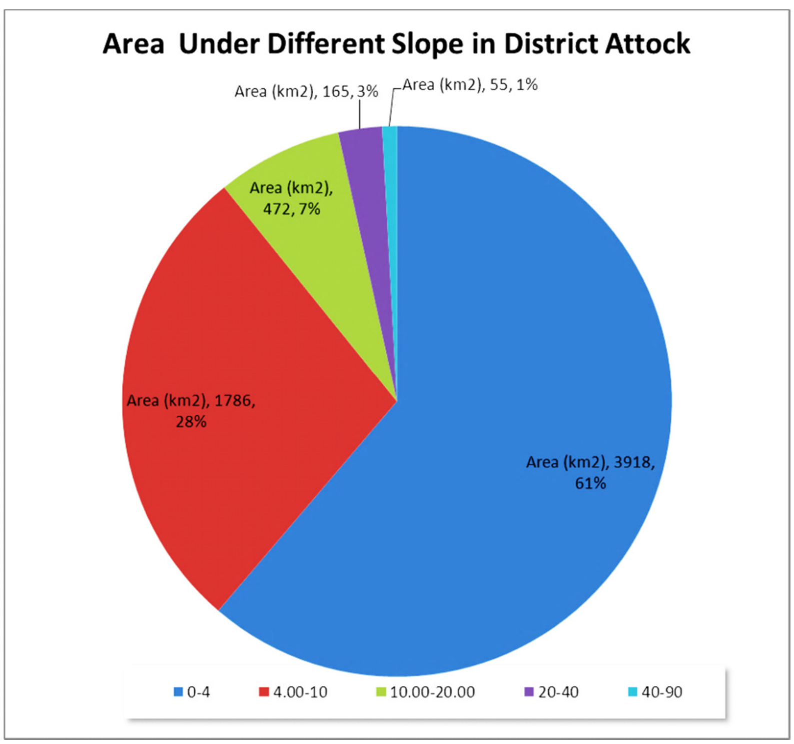
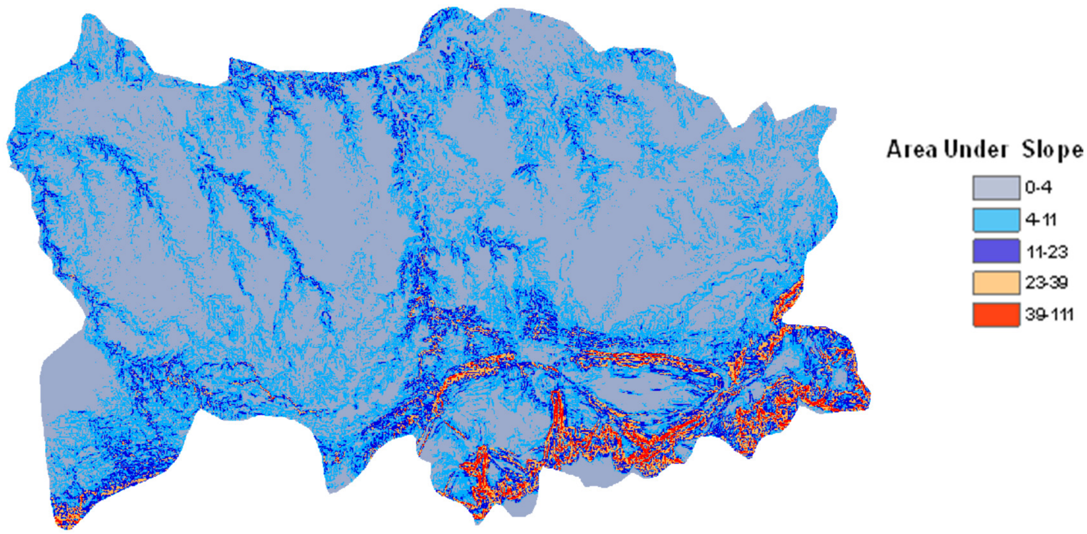


Figure 13.1 a) slope map of district Attock, 2) percent area under different slopes

13.3.2 Area under Different Slopes in District Chakwal

Similar to district Attock the topography of the district Chakwal was used to develop the slope (%) map, slope map was reclassified for different slope ranges (0-4%), (4-11%), (11-23%), (23-3%) and 39-111% respectively. The slope map shows that Chakwal has significant area (12%, 855 Km2) having slope more than 23%, this include mountainous area of salt range as shown in Fig 13.2.



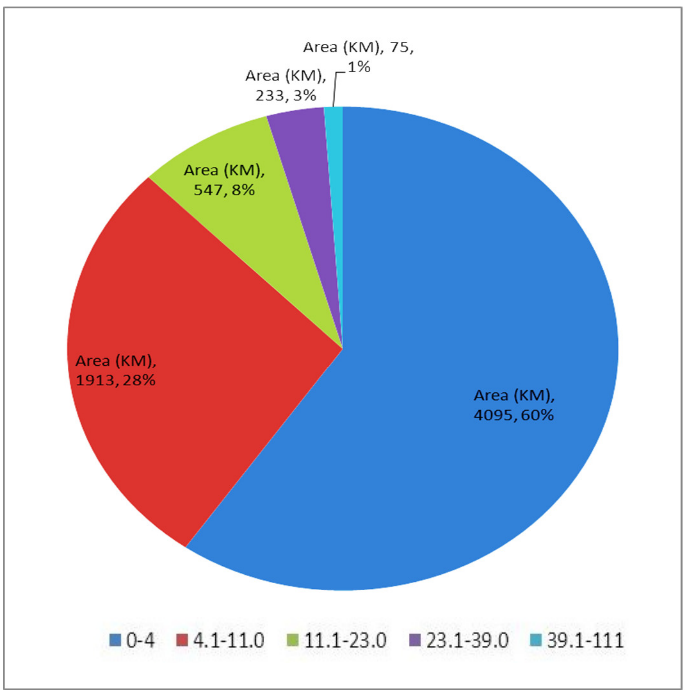


Figure 13.1 a) slope map of district Chakwal, 2) percent area under different slopes

Fig. 13.2 shows that 60 % area (4095 Km2) have slope 0-4% and 28% area (1913 Km2) lies in slope range 4-11%.
The total sediment yield reduction due to soil conservation structures was estimated for areas under different slopes in District Attock and Chakwal as shown in Table 13.6.

Table 13.6 Minimum and Maximum sediment yield reduction with structures at different slopes

Chakwal District					Attock District				
Slope (%)	Area (km^2)	Area (%)	Min Reduction SY	Max Reduction SY	Slope (%)	Area (km^2)	Area (%)	Min Reduction SY	Max Reduction SY
			Ton/year	Ton/year				Ton/year	Ton/year
0-4	4095	60	122850	7944300	0-4	3918	61	117540	7600920
4-10.1	1913	28	57390	3711220	4-10.1	1786	28	53580	3464840
10.1-20	547	8	16410	1061180	10.1-20	472	7	14160	915680
20.1-40	233	3	6990	452020	20.1-40	165	3	4950	320100
40-90	75	1	2250	145500	40-90	55	1	1650	106700

In district Chakwal minimum sediment yield reducing varies from 2220 T/y t to 122850 T/y and maximum reduction is 145500 T/y to 7944300 T/year, whereas in Attock minimum sediment yield reduction is 106700 T/y and maximum reduction is 7600790 T/y (Table 13.6).

Keeping in view topographic conditions, there is huge potential for implementation of soil conservation practice by installation of stone structures. However proper maintenance of structures is important for effectiveness.

13 Conclusions and Recommendations

- The loose stone structures for soil erosion control are effective options for soil erosion control in rainfed area. The model results show that 40% to 90% reduction in sediment yield due to structures.
- A final interpretation of quantitative model results may be misleading because no model can simulate all the physical process, soil and water interaction in real sense as these process occurs, some assumption have to be made, however the it can be suggested to the policy makers and planners that more 60% area in district Attock and Chakwal has potential for soil conservation due to stone structures.
- These structures require regular maintenance, because due non-meshing stones sliding occur, the displacement of one stone disturb the others also.
- The structure were not designed according to the hydraulic characteristic of flow available downstream energy dissipation arrangement, the downstream damage of the structures were common.
- Keeping view the ground conditions it is recommended that loose stone structures should be installed within slope range 0-10%.

- The wire meshed stone structures should be installed in the area slope 6-10%. There should be proper energy dissipation arrangement so that downstream erosion may not occur.

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