Application of SWAT model in the Estimation of Runoff and Sedimentation of Watrak River Basin, North Gujarat, India

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Abstract: The Soil and Water Assessment Tool (SWAT) was used to estimate runoff and sedimentation occurring in the catchment area of Watrak River, Northern Gujrat, India. In the present study, rain fall data of 31 years period (1987-2017) collected from 16 rain gauge (weather) stations was analysed and inputted in the SWAT model. Meteorological data was integrated in the model with topography, Soil and land use thematic maps. Aster Digital Elevation Model (DEM) was used for the delineation of boundary of Watrak River basin (catchment) and extraction of topographic features. In this area, yearly average rainfall varies from121 mm to 1252 mm. It suggests that there are intermittent drought periods within 31years period of study. More than average runoff was estimated by SWAT model study for the year 1990,1994 and 2006 which was 697.17mm,739.96mm, 607.24mm, respectively. Similarly, model results also indicated more than average sedimentation in the year 1990 (176.88 t/ha), 1994 (142.15 t/ha), and 2006 (180.8 t/ha). The average sedimentation estimated for the Watrak basin is 66.003 t ha^{-1} $year^{-1}$. The results of the SWAT model study of the Watrak basin suggest good correlation between rainfall and estimated runoff and sedimentation.

Index Terms– SWAT model, Sedimentation yield, Rainfall-runoff.

I. INTRODUCTION

Hydrologic models are used throughout the globe to simulate hydrologic methods including quality and quantity of stream flow in a watershed [1]. For hydrology model collection of the data requires extensive labour and cost. Therefore, it is required to simulate the hydrological condition of a catchment through hydrological models for long-term planning [7]. Thus, hydrologic models play an important role in simulating several hydrologic processes such as water quantity and quality, rainfall- runoff conceptualization, and sediment yield. Some of widely used hydrologic models include: Hydrological Simulation Program-Fortran (HSPF) [8], *Systeme Hydrologique Europeen* (SHE) [9], MIKE SHE [10], SHETRAN [11], Soil and Water Assessment Tool (SWAT) [12], Topographic Model (TOPMODEL) [13,14], and MOHID Land [2]. Of these, SWAT, a distributed process-based river basin continuous hydrologic model [12] is the most universally and widely applied tool for simulating hydrologic condition of the catchment for the long-term management [3]. This model has been used in the present study for the run-off and sedimentation analysis of the Watrak River basin using GIS technology.

II. STUDYAREA

The Watrak River basin (Lat 22.895^{0}to 22.924^0; Long 72.154^0 to 73.990^0) which is located in the Arvalli and Kheda district of North-eastern part of Gujarat state was selected as study area for SWAT modelling. The Watrak River originates in Panchara hills in Dungarpur district of Rajasthan and flows in southwest direction. This river joins Sabarmati river on left bank at Vautha (Lat 22.66^{0}N, long.72.537^{0}E) after travelling 248km through rugged terrain. Elevation in the area ranges from 8m to 544m.

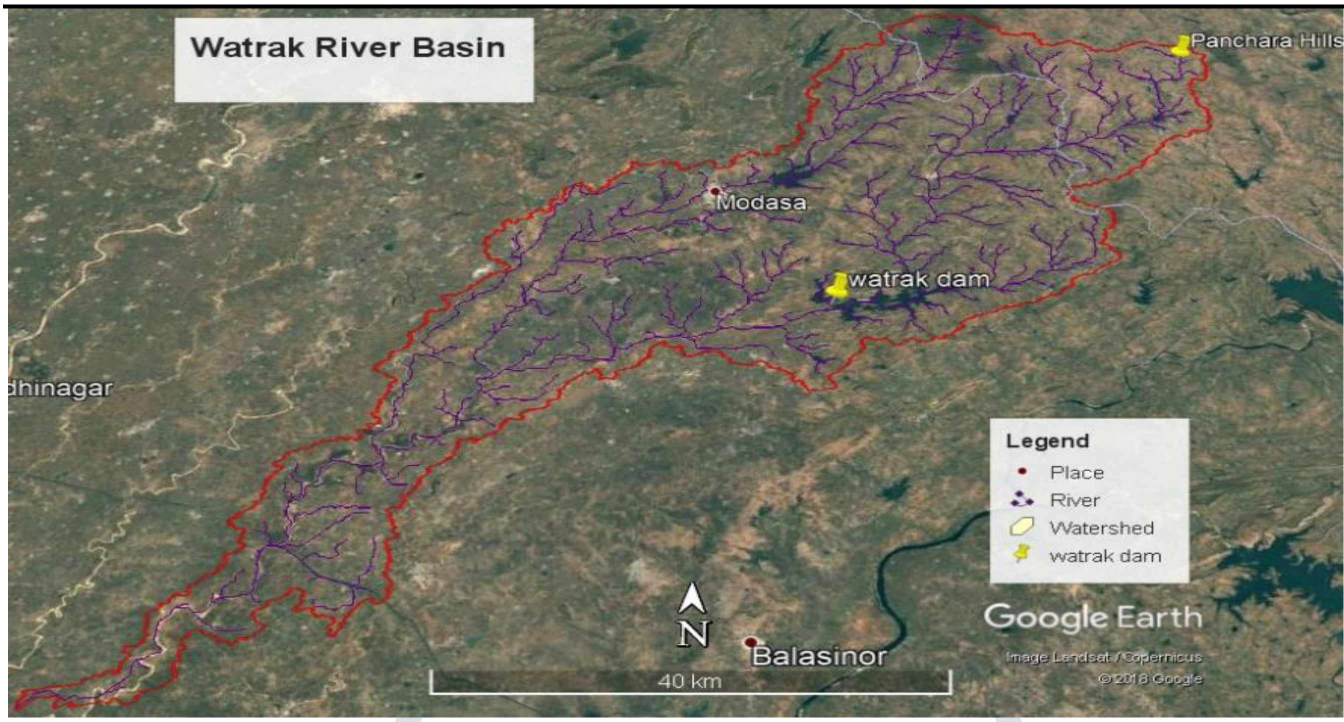

Fig. 1Watrak River Basin shown on Google Earth Image

Geology in the Watrak River basin comprises of phyllite, schist, Quartzite rocks of Arvalli group in the upper reaches and alluvium along valleys and in lower reaches near the confluence of Sabarmati River. These rocks exposed in the catchment area are folded faulted and sheared at places. Major part of the area is covered by loamy soil which consists of sand, silt and clay. Temp in the area varies from 8^0 C to 48^0 C, Average rainfall in the Waterak River basin is 690 mm in a year.

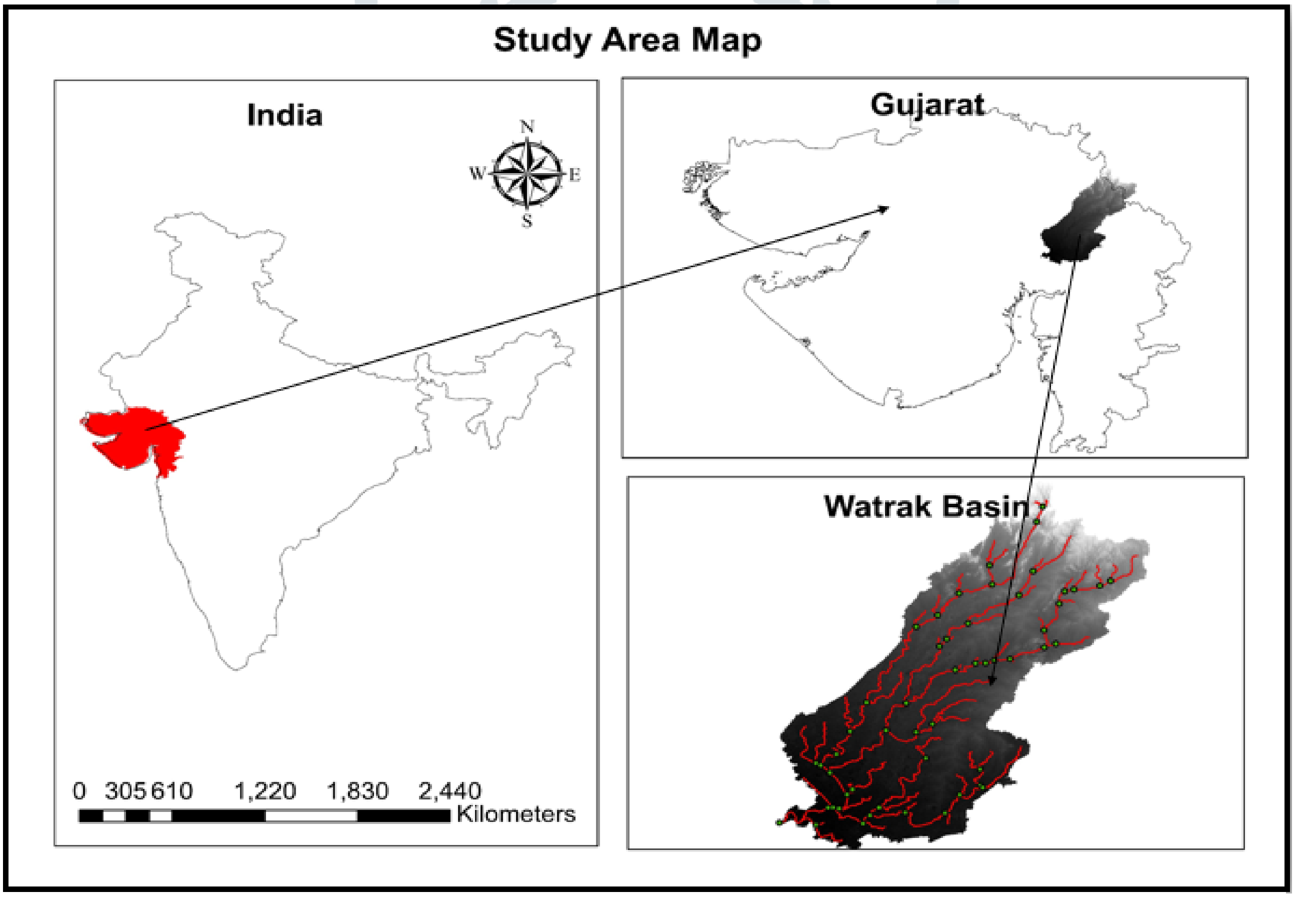

Fig. 2Location Map of Study Area

III. DATA USED

Rain fall data was obtained from the Indian Meteorological Department (IMD) (WWW.imd.govt.in). Soil map and land use map was prepared from the Google Earth and Landsat images in conjunction with the Irrigation Department data. Topography data was extracted from the Aster Digital Elevation Model (DEM).

1.**Soil map**

Soil map was classified into five classes (Fig…): (1) Clayey skeletal (1.3% of total area), (2) Coarse loamy (24.35%), (3) Fine loamy (60.2%), (4) Loamy (1.54%) and (5) Loamy skeletal (12.5%).

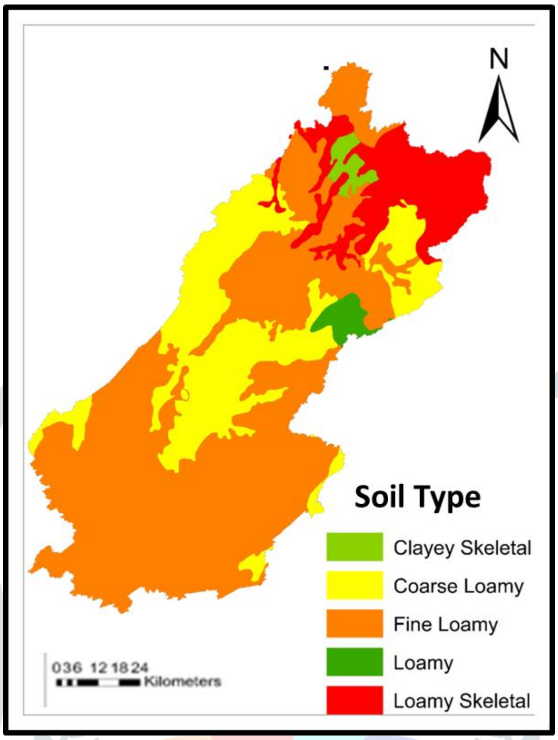

Fig. 3Soil Map of Watrak basin

2.Land use map

Land use map was classified into six classes: (1) Agriculture (86.8 % of total area), (2) Barren land (0.45%), (3) Built-up (1.93%), (4) Forest (1.19%), (5) Wasteland (7.84%), and (6) Water bodies (1.77%).

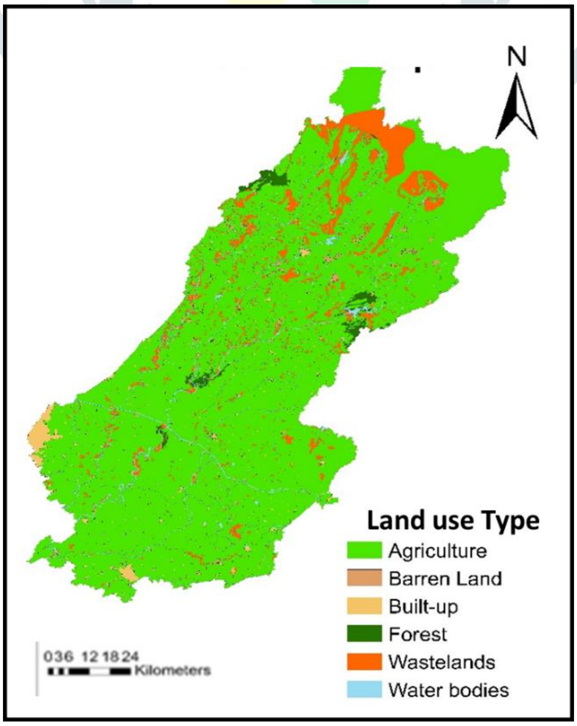

Fig. 4Land Use Map of Watrak Basin

3. Meteorological data

Meteorological data such as daily precipitation, maximum and minimum temperature and wind speed was collected from16 weather stations as input parameters in the SWAT model. This data for 31 years period (1987-2017) was used in the model study.

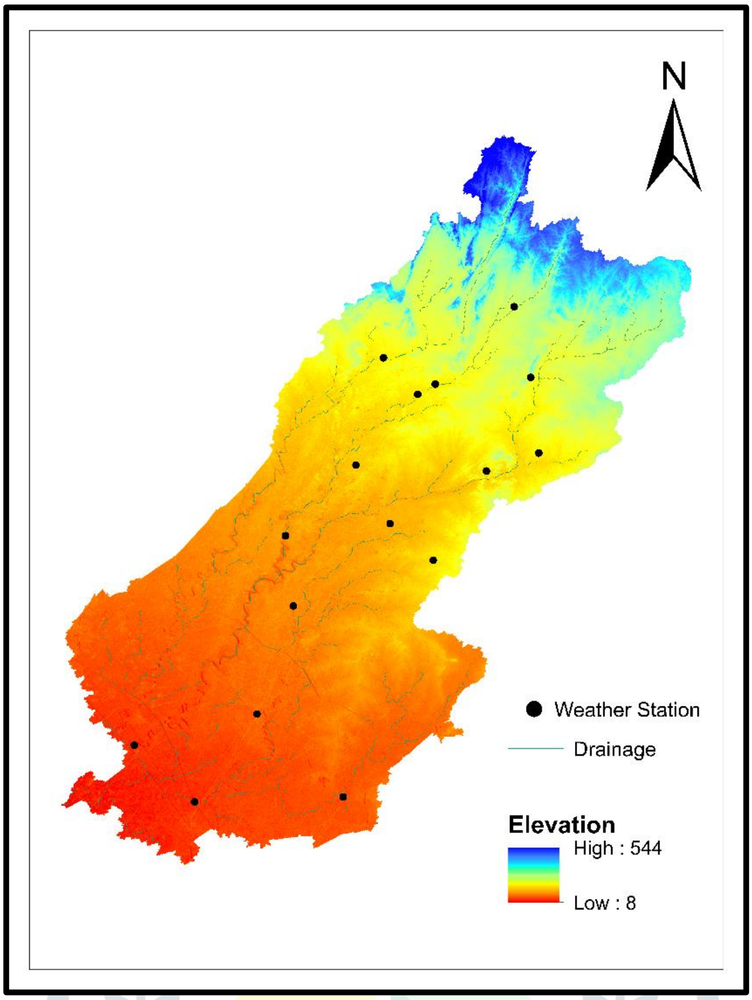

Fig. 5Location map of weather station

IV. Methodology:

Following are the main steps of the SWAT model application for the sedimentation analysis:

- Creation of new project in software and setting of project path.
- Selection of tool of Automatic Watershed Delineation to delineate sub basin and basin.
- Creation of Hydrological Response Unit (HRU) by uploading Soil, land use and Slope thematic maps of the basin.
- Inputting (integrating) Rainfall, Temperature and wind data (text file) in write input file.
- Creation of parameters tables.
- Running of SWAT model
- Results of the model study.

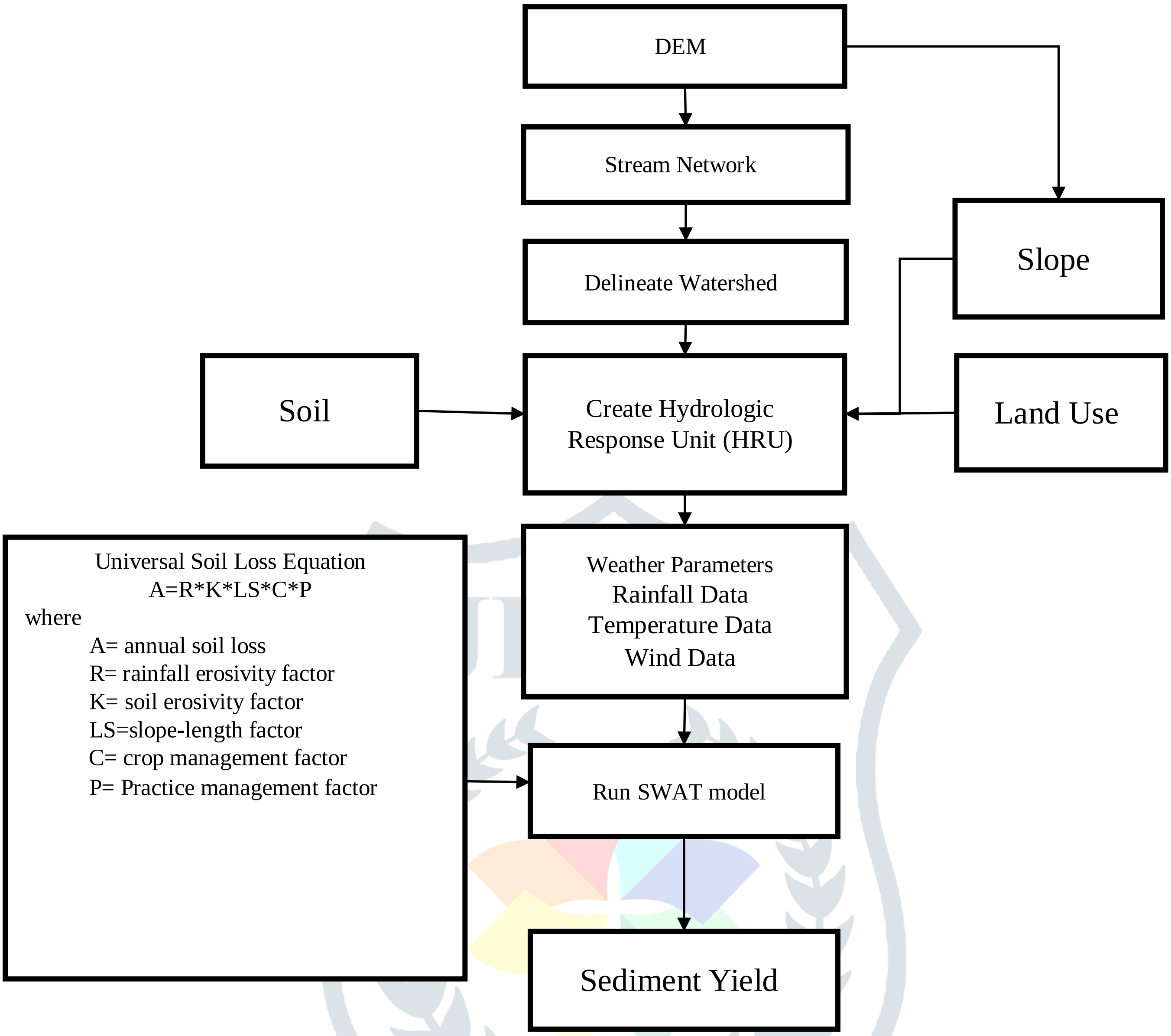

Fig. 6Flow chart of SWAT model methodology

1. Model Setup:

The SWAT model set up was done into four main steps (Winchell et al., 2010): (1) watershed delineator, (2) HRU analysis, (3) write input tables, and (4) edit SWAT input

2. Watershed Delineator

A total number of 113 outlets and sub basins were defined based on the primary drainage extracted from DEM (Fig. 7). It included delineation of basin boundary. Within this drainage basin boundary eight thematic layers namely soil, geology, land use, runoff, topography, channel erosion, and upland erosion were created and integrated. Each layer was giving specific numerical grade based on the observation and practice. Based on the sum of these grades' drainage basin was classified and annual sediment yield per unit area of the basin was estimated using GIS.

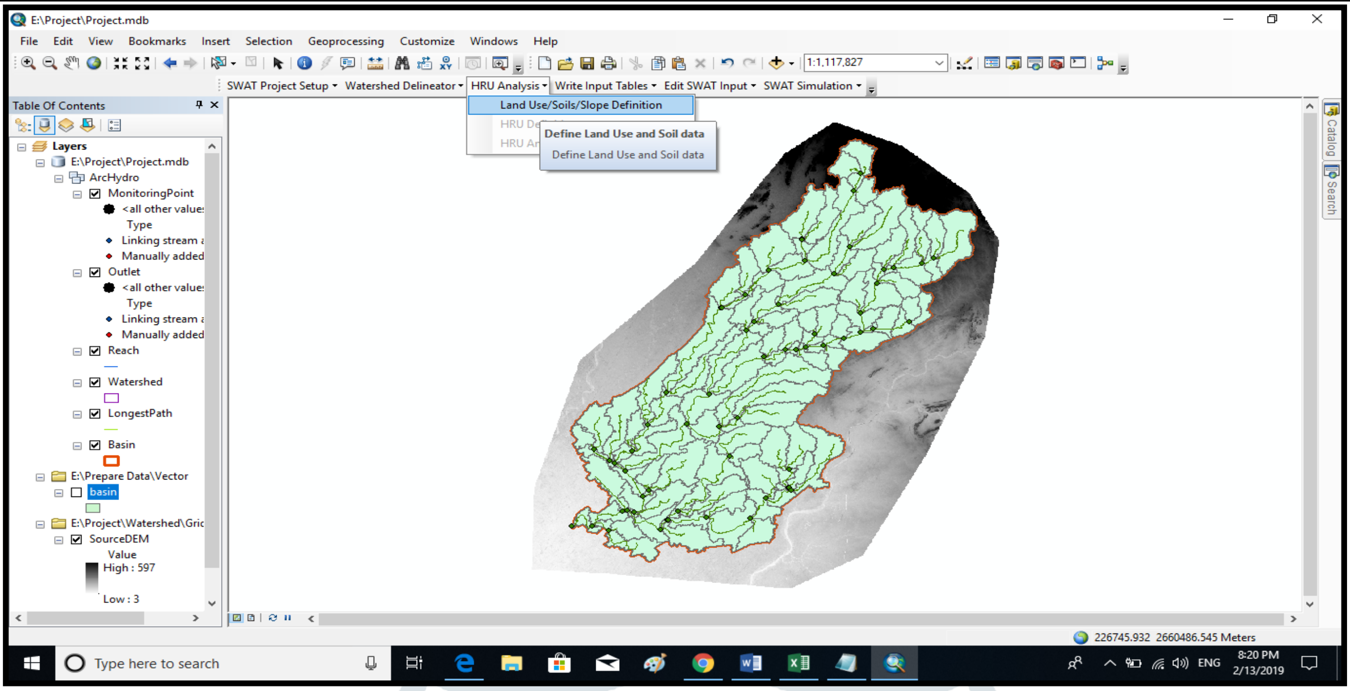

Fig. 7Automatic watershed delineation in SWAT

3. HRU Definition

Hydrologic Response Units (HRUs) for the sub basins were defined based on three parameters: land use, soil types, and slopes with various thresholds.

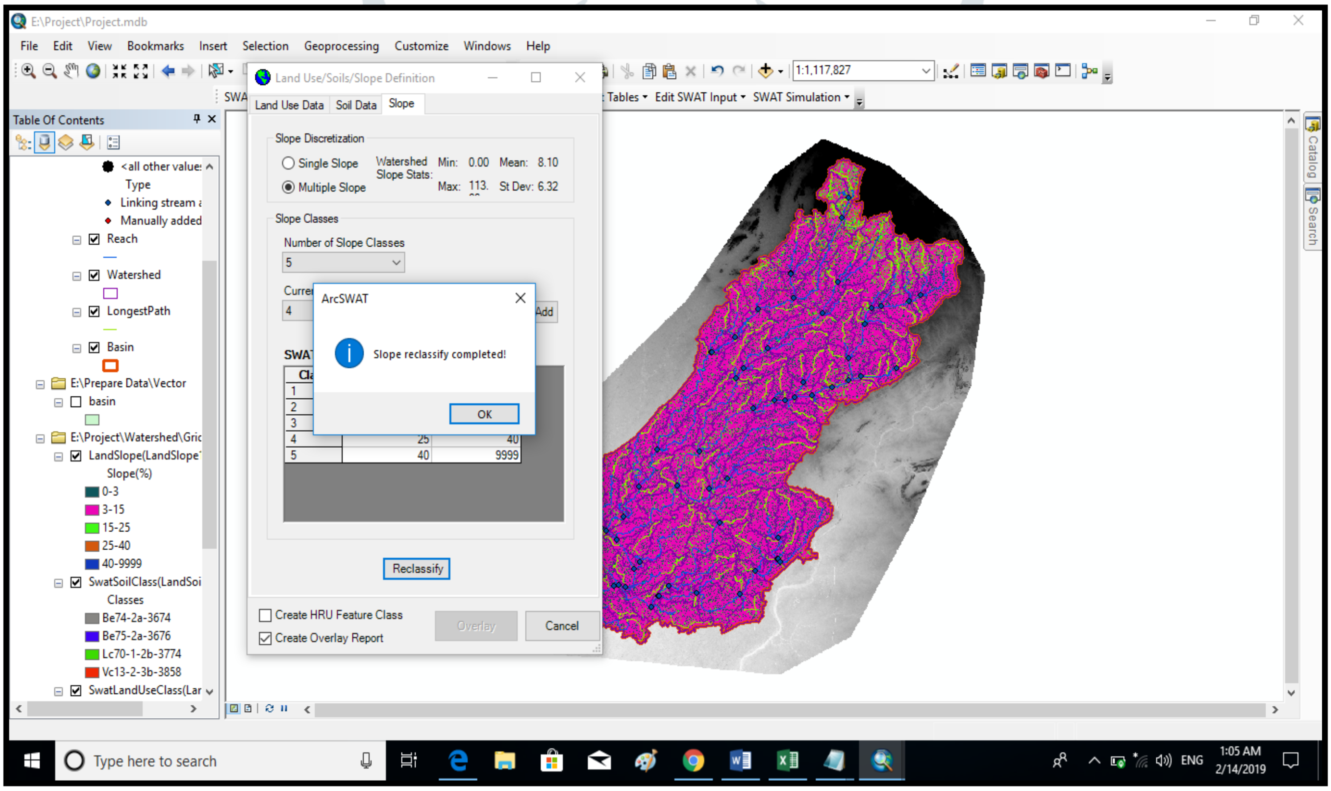

Fig. 8Land Use, Soil and Slope Definition

In the present study, land use data was classified in to 5 land use types (Figure.8). The SWAT database file for soil layers was created from the soil datasets in the format of global soil dataset. The slope map was reclassified into five slope classes for each catchment with the threshold value as 0% to consider all parameters. These reclassified slope layers were overlaid to define HRUs (Figure 9.).

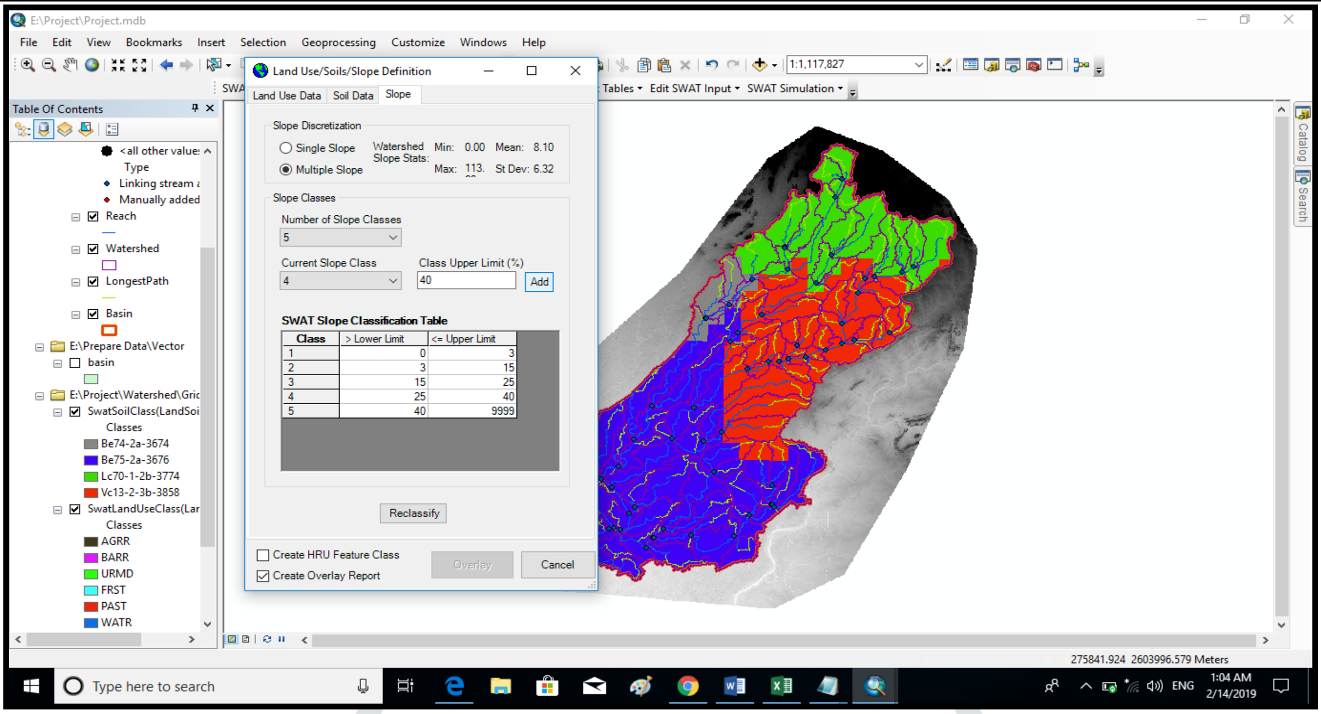

Fig. 9 Definition of the five slope classes which were defined in HRU

In the present study multiple HRU's in each sub basin were used based on the land uses, slopes and soil types as per Winchell et.al. 2010 threshold criteria for the simulation of model as below (Figure.10):

- Land use percentage (%) over sub-basin area = 0%
- Slope class percentage (%) over soil area = 0%
- Soil class percentage (%) over land use area = 0%

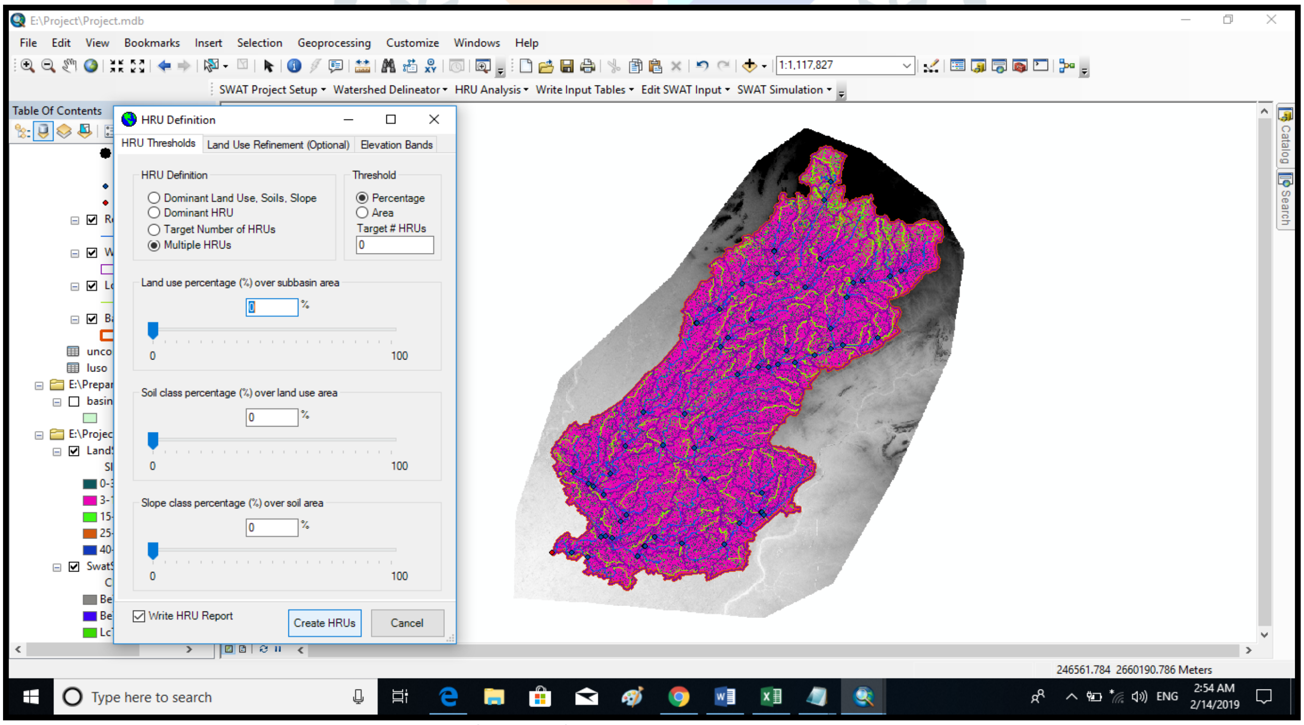

Fig. 10Definition of the Hydraulic Response Units (HRU)

Finally, report was generated with land uses, soil types, and slope features for the entire Watrak River basin.

4. Weather Data Definition

In the SWAT modelling weather data required include precipitation, evaporation, relative humidity, temperature, solar radiation, and wind speed. In the present study we customized soil and climate database as per Indian condition instead of built in US database. For the Watrak River basin, rainfall data for 31 years period was used and wind speeds were created by WXGEN which is a SWAT built-in weather generator. Datasets obtained from the SWDC and Indian Remote Sensing Website (Web address) were also analysed. These data from the SWDC and Indian remote sensing give improve results, so they have been used to increase the model efficiency.

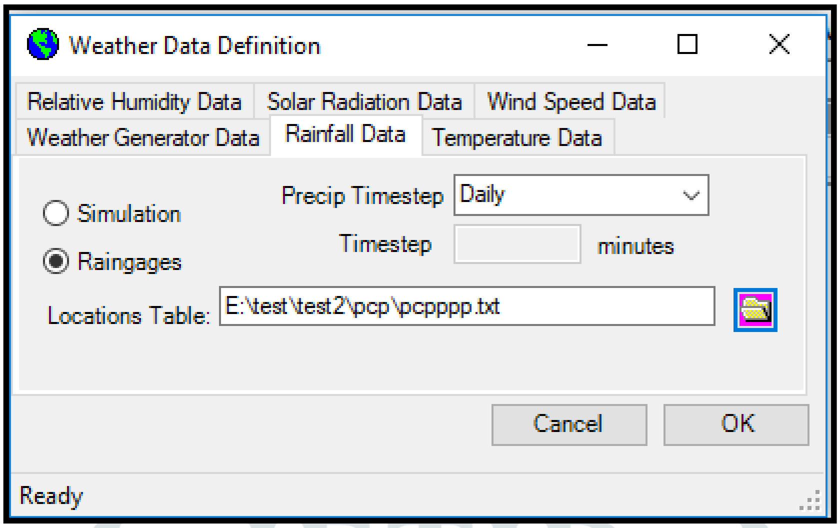

Fig. 11Weather data definition menu in Arc-SWAT interface

Finally, observed data on min/max daily precipitation and temperature was loaded into the model to increase efficiency because weather data, mainly rainfall, have great effect on model execution as run-off mainly depends on the precipitation (Abbaspour et. al., 2007).

5. Write Input Tables

The input files in FORTRAN format were of the soil data, land use, and watershed boundary were used in the model by selecting 'write all files' option. In the present study to build primary watershed input files, the default parameters were kept in SWAT and the default value of Manning's n (0.0012) was used.

6. Run SWAT Simulation

The SWAT simulation menu was set to dates: 01/01/1987 and 12/31/2017 with a yearly printout. The rest of the parameters were left as default values. Finally, the simulation of model was run (Figure.12) Results of the watershed values were obtained through the "output.std" text file and documented in Microsoft Access format.

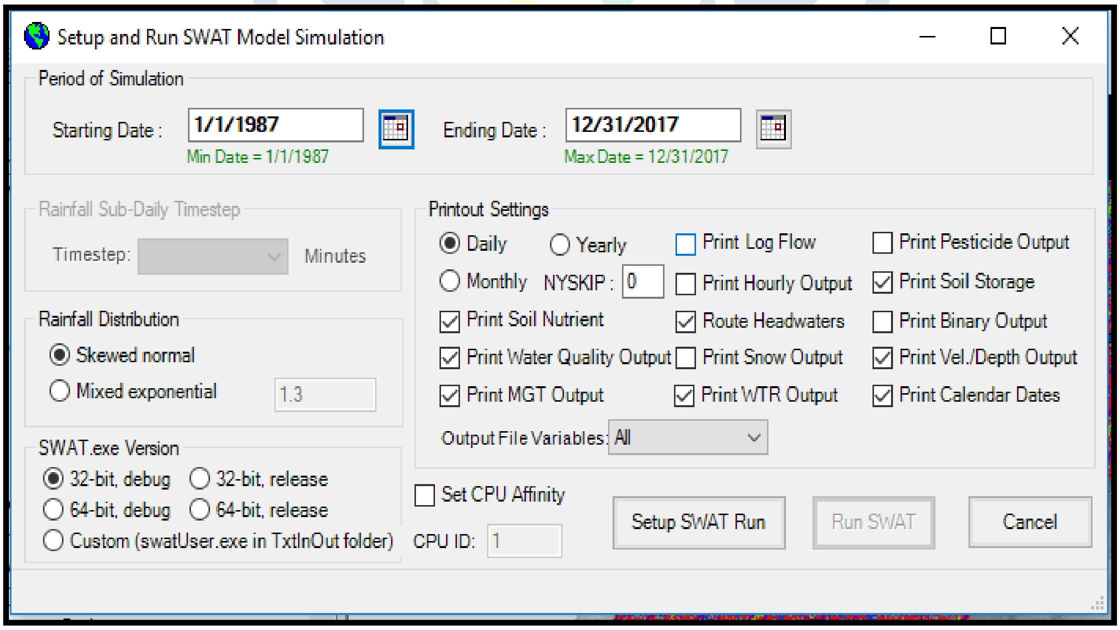

Fig. 12SWAT model setup and simulation menu

V. RESULTS AND CONCLUSIONS:

In the present study the Soil and Water Assessment Tool (SWAT) was used to estimate runoff and sedimentation in the catchment of Watrak River basin. In the model study topography, soil, land use; and meteorology data of the study area for 31years (1987-2017) was used as input parameters. In total 103 sub basins were delineated in the Watrak River basin having 764761.48 ha area using ArcSWAT from Aster DEM of the catchment area. Thematic maps namely Land use and soil maps were generated and loaded into the ArcSWAT model for HRU analysis. These thematic maps and slope maps were reclassified into appropriate classes using natural break method in GIS for the analysis in ArcSWAT model. Evapotranspiration and other hydrologic parameters were calculated using Hargreaves method (SWAT user's guide,2010) and integrated with meteorological data in the SWAT model.

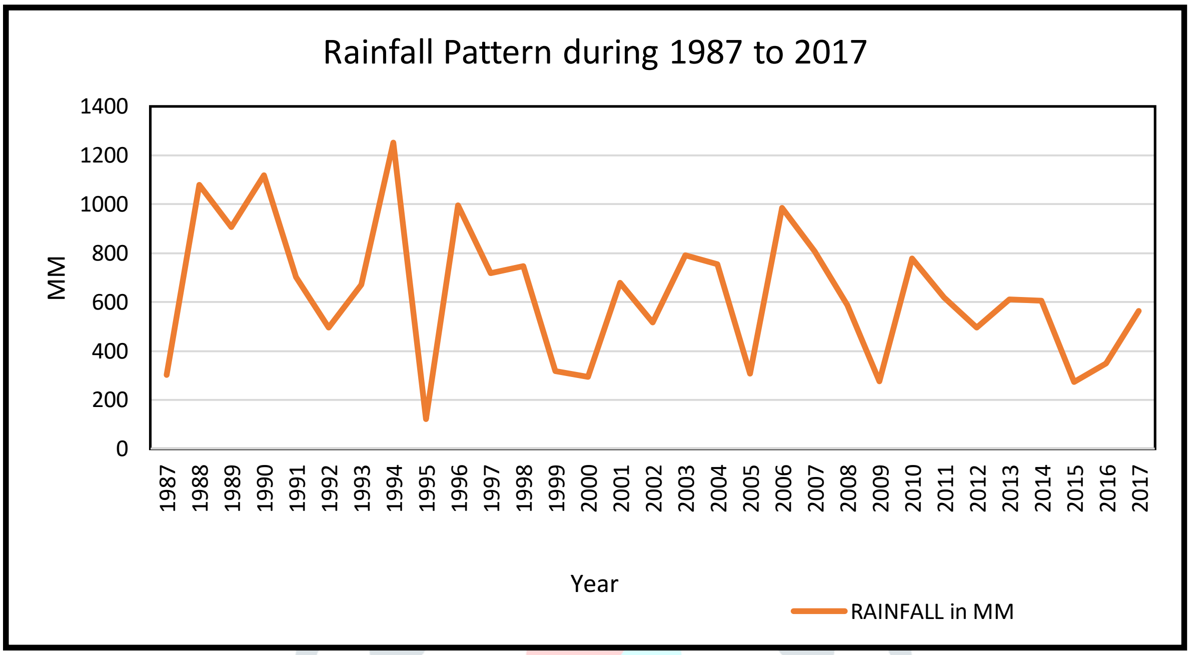

Fig. 13Avg. Annual Rainfall pattern during 1987 to 2017

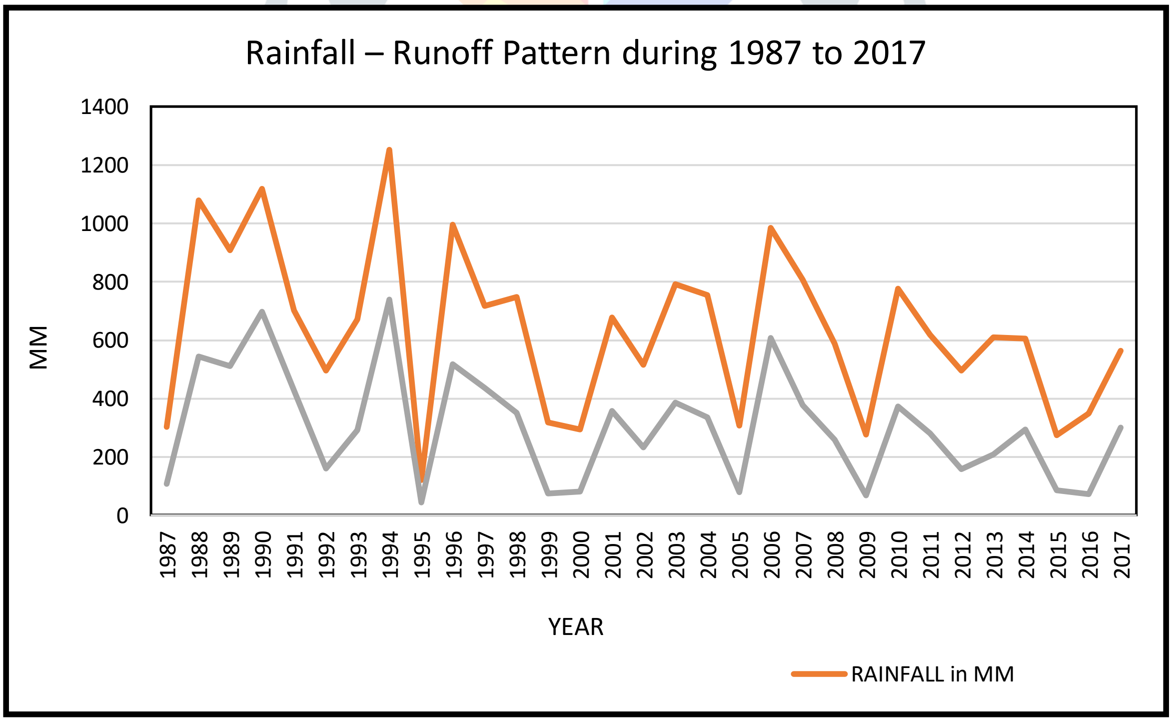

Fig. 14Avg. Annual Rainfall-Runoff pattern during 1987 to 2017

Comparison of the rainfall-runoff data with the sedimentation data reveal that generally runoff increases with the increase of rainfall and consequently sedimentation in the catchment area (Fig.14). The maximum runoff was estimated to be 697.17mm,739.96mm, 607.24mm for the year of 1990,1994 and 2006, whereas corresponding sedimentation estimated is 176.88 t/ha, 142.15 t/ha, 180.8 t/ha, respectively in comparison to average sedimentation 66.003 t ha^{-1} $year^{-1}$ in the Watrak basin. Model results indicate that in the year 1990, 1994 and 2006 rainfall, runoff and sedimentation was more than normal (66.003 t ha^{-1} $year^{-1}$) in the Watrak River basin which suggest greater erosion/ degradation of the land in the catchment area. However, sedimentation rate of different years is required to be verified from the instruments data. The present study of SWAT model would be helpful in the proper management of not only Watrak River Basin but other catchment areas of India as well as other basins of the world.

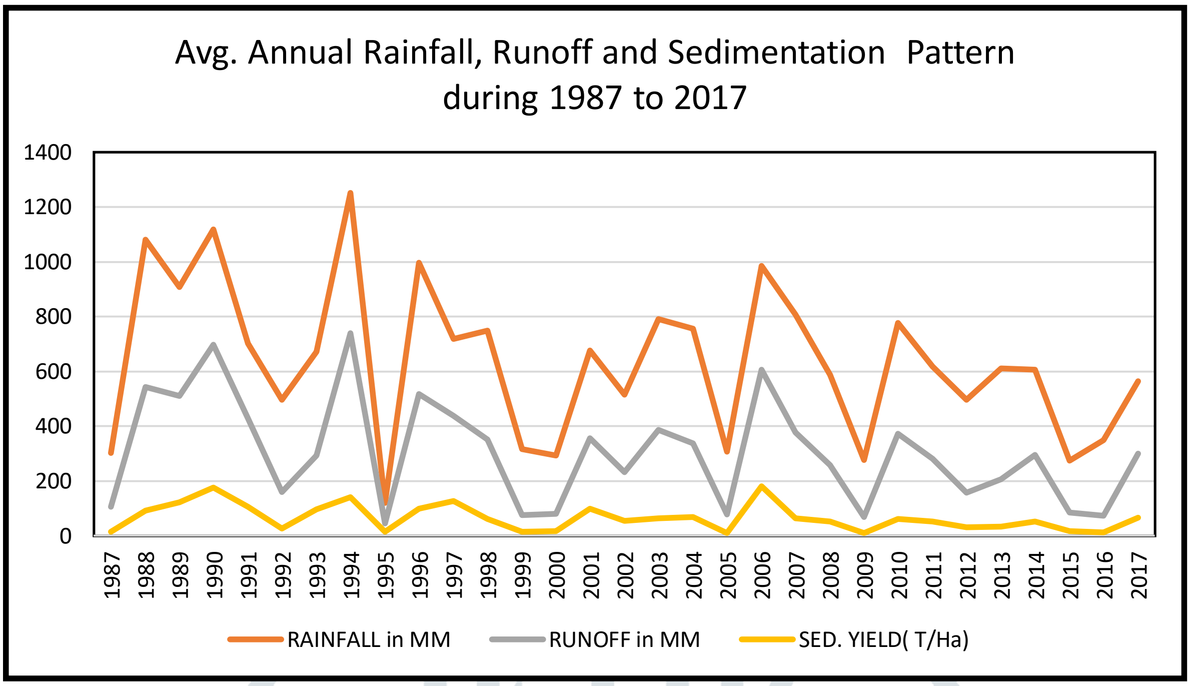

Fig. 15Avg. Annual Rainfall, Runoff and Sedimentation pattern during 1987 to 2017

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