Utilizing SWAT for Surface water discharge Modeling: a case study of a watershed in Ganga basin

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Abstract:
Water issues in Uttar Pradesh are stressed due to rising population and climate change. The studies showed that in future the changing climate and intense human activities would complicate the situation endangering the water and soil resources. To support sustainable uses of these resources an appropriate model is required in this area, and to develop such model runoff, evapotranspiration and soil erosion modeling is essential. In this paper Soil and Water Assessment Tool (SWAT) is used to model hydrological processes of a watershed in ganga basin. Ten years of daily meteorological data, soil data procured from National Bureau of Soil Survey(NBSS), Digital Elevation Model of ninety-meter resolution and Landsat 8 satellite imagery are used as inputs. The watershed was divided into 39 subbasin for analysis and modeling. The Sufi-2 algorithm was used for validation and calibration. The data was divided into two halves of five years each. First half was used for calibration and second half foe validation of model.The results revealed that more than half of the annual precipitation Water is lost in evapotranspiration and runoff. Sediment yield of various soil erosion-prone areas was estimated. The results from modeling were further used to propose and model multiple water conservation and Sediment filtration basin structures in the flood and soil erosion impacted areas This study also revealed that how SWAT model is valid to be used in Hydrological and soil erosion Modeling. These results can be further implemented for water conservation structure, drainage management of Varanasi.

Keywords: Runoff, Soil erosion, SWAT, watershed, evapotranspiration

1. Introduction

Water & soil are fundamental sources for sustainable economic and social development. Over the years, because of the anthropological activities such as growing population, land-use change, environmental pollution, climate change, etc. Water scarcity, flood and soil erosion have become the significant hitches for the sustainable development of communities all over the world. With substantial climatic changes in the world, the precipitation and evapotranspiration patterns are significantly affected and so is the distribution of water. In some areas, the water table in the subsurface rises and results in flooding, while in others it declines due to scarcity in both surface and underground. Rising temperatures are causing more evaporation and demand for water and by agriculture and natural ecosystems. Warming lakes and streams are beginning to devastate fisheries and change water quality and living conditions for many aquatic organisms. The evidence of change is all around us, and not just in the form of the rapidly rising thermometers that are the most commonly cited evidence of the greenhouse effect. Extreme precipitation events are becoming more frequent and damaging. Therefore, attention needs to be paid to the management of these resources, especially to the affected river basins. The need of the hour is to find ways to conserve and manage water such that future generation can also make use of these resources. Water & soil conservation is a sound way to overcome these problems.

Even without climate change, the world has plenty of severe water challenges. Seven hundred million people lack access to safe and affordable drinking water. More than two billion lack adequate sanitation. Droughts and floods are already the most damaging extreme natural events for society. In some regions, the severity and frequency of droughts can lead to water scarcity situations, while overexploitation of available water resources can exacerbate the consequences of droughts. Water scarcity involves water crisis, water shortage, water deficit or water stress. It can be due to physical water scarcity and economic water scarcity. The leading causes of water scarcity are overuse of water, pollution of water, drought, etc. Droughts are becoming more severe under the influence of climate change. Rising sea levels will increasingly damage coastal wetlands as well as devastate communities that cannot afford to build massively expensive coastal defenses or to relocate.

During the past few years, a number of hydrological models such as Agricultural Non-Point Source Pollution (AGNPS), System Hydrologic European (MIKE SHE), and Soil and Water Assessment Tool (SWAT) have been developed and are used to simulate hydrological processes[11,7,2,9] . Among these models, the SWAT can be used to estimate the climatic changes in a sound and proper way, so that we can adapt to and reduce the effects of climate change effects. The SWAT model is a physically based & continuous model developed by the USDA Agricultural Research Service (ARS)[1] . The model is applied to hydrological modeling, runoff and soil loss prediction, water resource management, water quality modeling, land-use change affect assessment and climate change impact assessment.[5] integrated the SWAT model with geospatial techniques like Remote Sensing & GIS for modeling runoff and sediment yield for Khadakohol & Harsul watersheds in Maharashtra, India. scientist have proposed a modified form of SWAT for the identification of areas to improve downstream water quality[3]. Some have applied the SWAT to simulate hydrological and water quality effects of land-use and management practices in the Neshanic River watershed, a typical, mixed land use, suburban watershed in Central New Jersey, U.S.[6]. However a researcher used the Soil & Water Assessment Tool (SWAT) to model the hydrology and to categorise acute erosion-prone regions of the Barakar Basin in Jharkhand state, India [8]. coupling of the Soil & Water Assessment Tool (SWAT) 2005 with a GIS interface (AVSSWATX) to Kosynthos River watershed situated in Northeastern Greece [6]. Modeling of the hydrological stream course with the use of the Soil & Water Assessment Tool (SWAT) model in the Xedone River basin, in the Southern part of Laos is also done [10].

In the present study, availability of Digital Elevation Models (DEMs) & satellite data was procured through USGS; land use & land cover maps were prepared using Erdas IMAGINE; soil type data was prepared using ArcGIS; precipitation, temperature, solar radiation & crop type data were obtained from Indian Metrological Data (IMD). SWAT model was applied to a part of Ganga River, which covers 11 districts in the Eastern Uttar Pradesh, India for watershed delineation. For this purpose, the watershed was divided into sub-watersheds. Hydrological Response Unit (HRU) analysis was performed. Calibration and validation were implemented at the sub-watershed and watershed level. Finally, runoff, sediment yield & evapotranspiration data were estimated. The specific objectives of the study were (I) Data collection (II) Classification (III) Look-up table creation (IV) Data modification (V) Data analysis (VI) Calculation using SWAT (VII) Result.

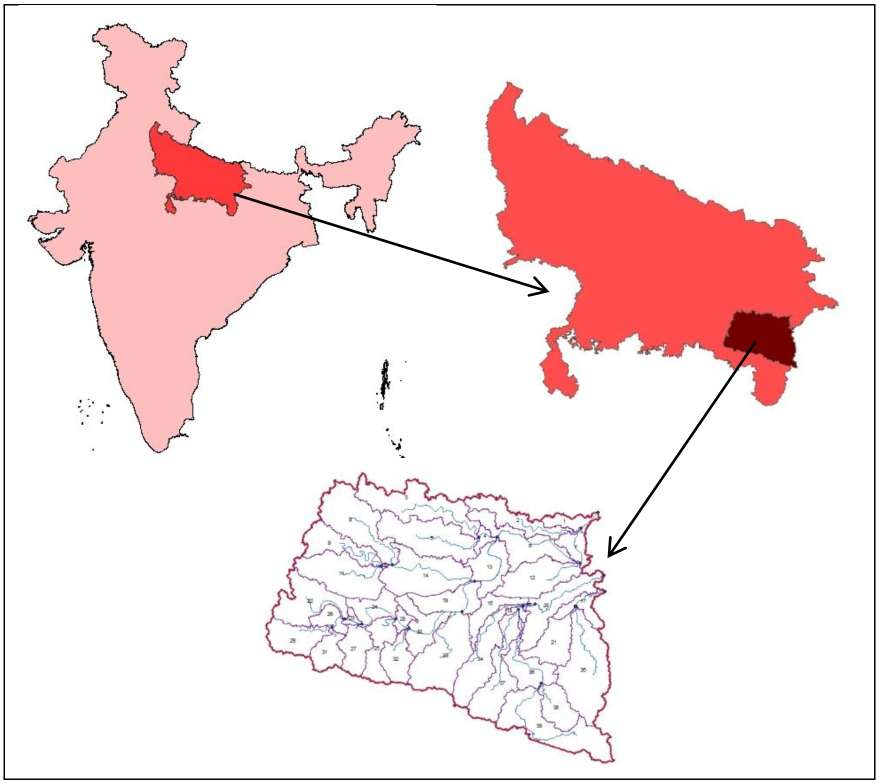

Fig. 1: Study area

2. Study Area

River Ganga, the longest river in India, flows across several significant states of the Northern part of the country, covering the length of about 2,500 kilometers. In this study, a watershed from the Eastern Uttar Pradesh was taken into account, which lies in the lower Ganga Basin and covers three major districts of the state. The total area of the study area is about 480 km2. The length of the river was 35 kms in this watershed. The latitude and longitude parameters of the basin lie between 26°58'14.75"N, 80° 2'38.94"E to 24°31'45.02"N, 84°41'1.17"E.The Fig 1 given below describes the study area.

3. Data Used

Following data was used for this project:

- Satellite imagery of Landsat 8 was procured from USGS. The latitude & longitude parameters of the image are respectively.
- SRTM DEM of 90m resolution was procured from USGS. The maximum and minimum elevation of the DEM are 719 and 19 respectively.
- Daily precipitation, solar radiation and temperature data of 10 years was procured from Indian Meteorological Department (IMD).
- Soil data was provided by National Bureau of Soil Survey & Land Use Planning (NBSS).

4. Methodology Used

The Fig 2, given below explains briefly the methodology and steps followed in this project.

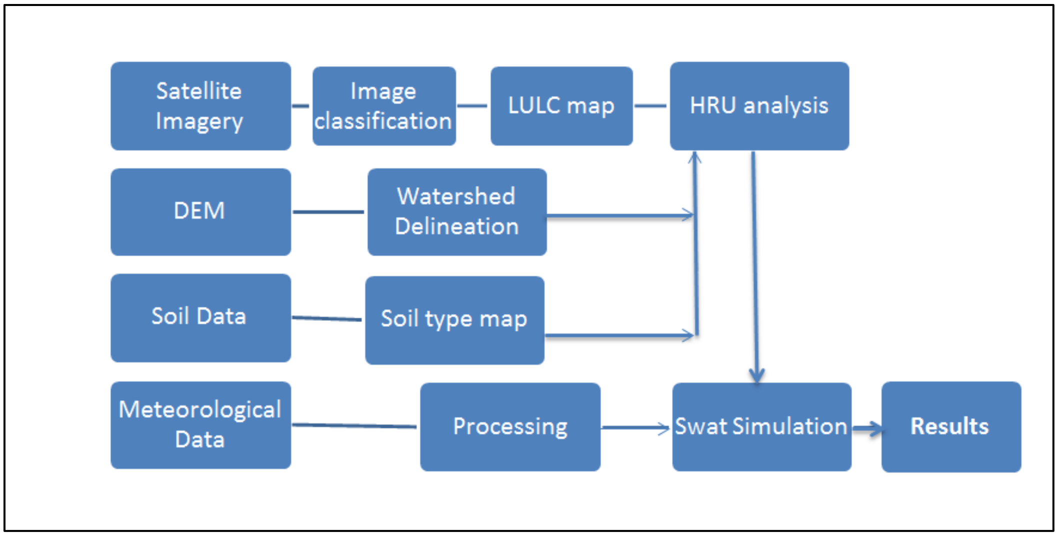

Fig. 2: Methodology

Soil & Water Assessment Tool (SWAT) model is used to estimate the surface discharge, sediment yield and evapotranspiration. The equations used by this model are Water budget equation, SCS-CN method and Universal Soil Loss Equation (USLE). ArcSWAT is one of the extension of ArcGIS, which is based on SWAT model and is very helpful for hydrological modeling as well as sediment yield modeling.

SWAT is based on following equations-Water budget equation: It is given as

$$P = R + E + \Delta S$$

where, P is precipitation, R is streamflow, E is evapotranspiration, and ΔS is the change in storage in soil.

This equation uses the principle of conservation of mass in a closed system, whereby water entering a system, must be transferred into either evaporation, surface runoff, or stored in the ground.

SCS-CN method: Soil Conservation Service Curve Number is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. The stat requirements for this method are very low rainfall amount and curve number. The general equation for the SCS curve number method is as follows:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S}$$

where, Q is runoff (in), P is rainfall (in), S is maximum potential retention after runoff begins, and Ia is initial abstractions.

$$Ia = 0.2S$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$S = \frac{1000 - 10}{CN}$$

This method can be used to find average annual runoff values.

Universal Soil Loss Equation (USLE): It is a method to predict soil average annual soil loss caused by sheet and rill erosion. It is given as

$$A= R*K*L*S*C*P$$

where,

A= average annual soil loss in t/a (tons/acre),

R= rainfall erosive index,

K= soil erodibility factor,

LS= topographic factor-L is for slope length &

S is for slope,

C= cropping factor, and

P= conservation practice factor.

4.1 Inputs prepared for ArcSWAT

- Satellite image, Digital Elevation Model (DEM), meteorological data was procured.
- Supervised classification was done using Erdas IMAGINE for preparing land use and land cover map. Six classes were created as shown in Fig 3.
- Soil type map was prepared using ArcGIS 10.
- Look up table for land use/ land cover soil type was created.
- Meteorological data was prepared as required for ArcSWAT input in .txt format.

4.2 Steps Followed

- Watershed delineation was performed using DEM which involved the division of watershed into 39 sub watersheds showed in Fig.4.
- Hydrological Response Units (HRU) analysis was conducted using LU/LC maps along with soil map. 35 HRUS were created.
- All the meteorological data was given as input wherein the SWAT database was updated.
- SWAT simulation was carried out.
- Run SWAT model.

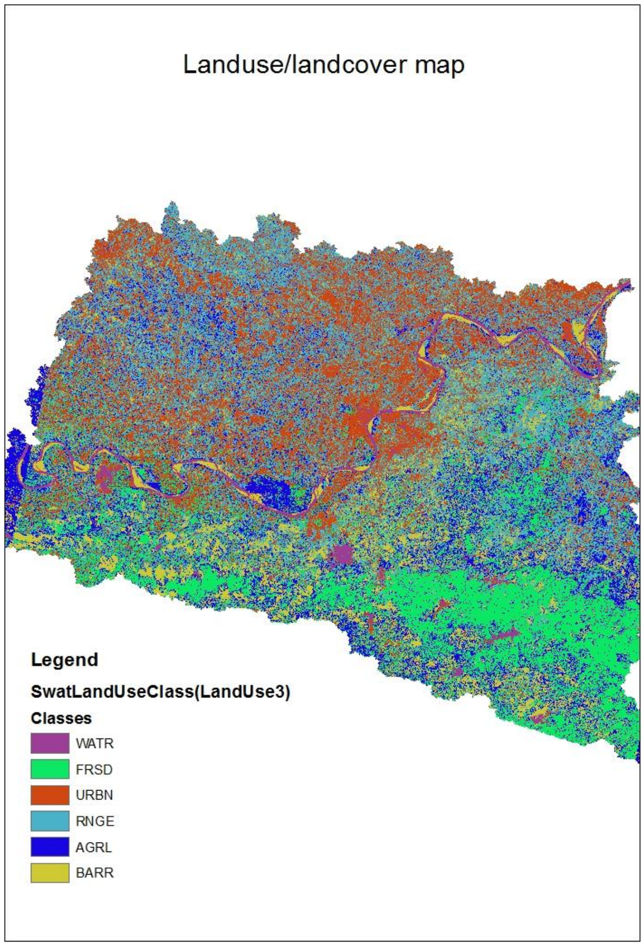

Fig. 3: Land Use and Land Cover

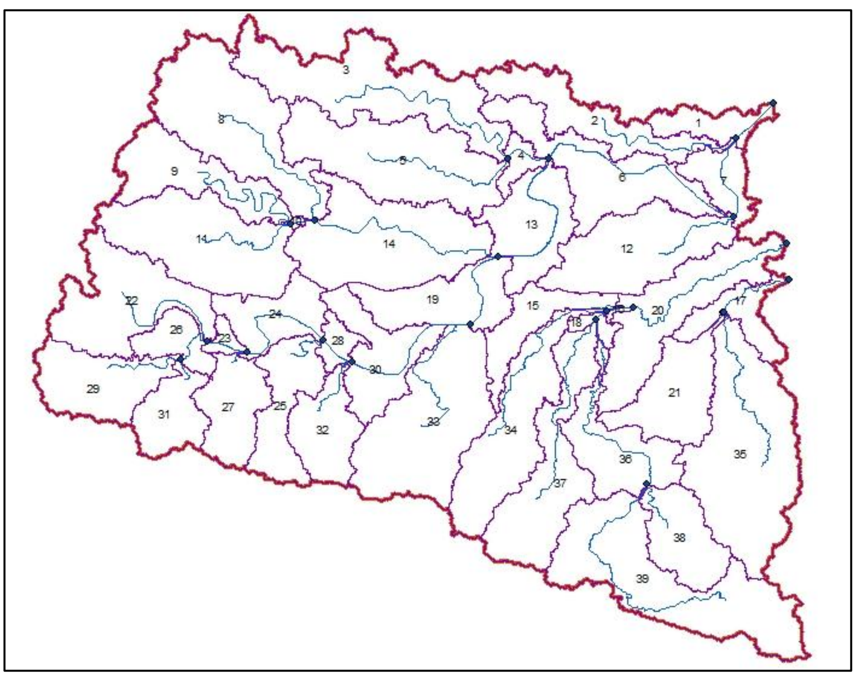

Fig. 4: Sub-Watersheds

5. Results

Ten years of daily data was taken for the analysis and modeling. The table 1 shows the average discharge, precipitation, evapotranspiration and sediment yield values of the basin on monthly basis. Maximum values were seen in the month of June. By the result it was found that more than 50 percent of precipitation water was used in evapotranspiration and Surface discharge.

Table 1. Average Monthly Basin Values

Month	Rain	Surface Runoff	Evapotranspiration	Sediment Yield	Potential Evapotranspiration
	(MM)	(MM)	(MM)	(T/HA)	(MM)
1	74.79	14.7	27.85	145.64	45.4
2	83.71	20.97	31.3	2.18	51.17
3	100.43	26.41	48.01	1.83	87.5
4	82.8	18.86	61.11	1	119.48
5	115.87	31.07	86.48	1.25	152.24
6	3018.24	2647.03	107.93	30.68	187.87
7	86.89	13.81	111.35	0.52	205.25
8	95.39	17.27	83.9	0.23	183.08
9	105.74	18.26	60.14	0.31	145.11
10	98.04	20.12	43.3	0.77	111.22
11	93.19	20.78	32.13	0.95	64.36
12	1364.51	794.33	26.66	29.76	44.27

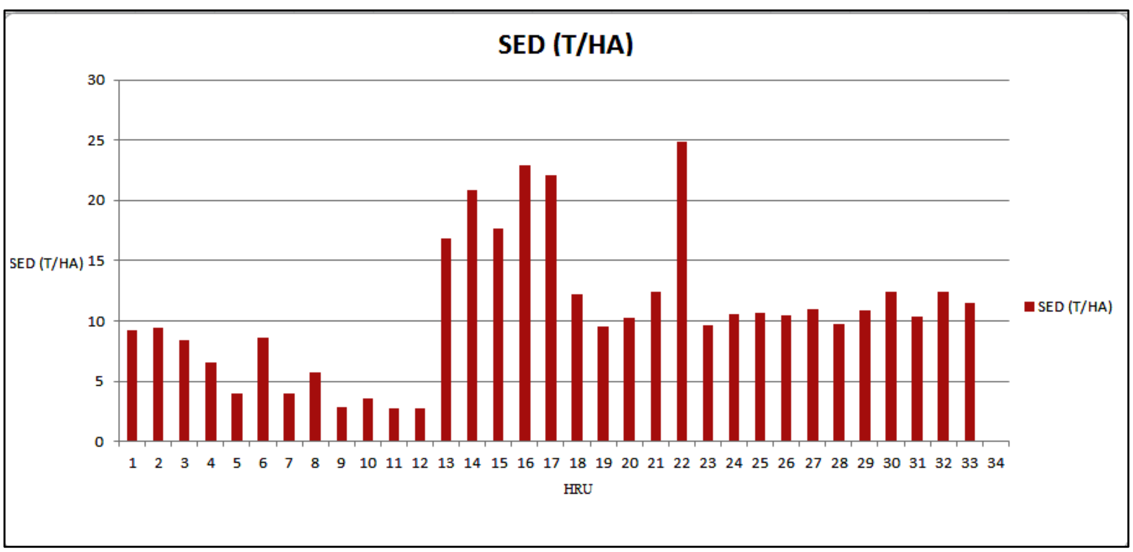

Fig. 5: Sediment yield per HRU

Fig 5 shows the graphical result of sediment yield values of thirty five HRUs, the maximum value was for HRU 24.

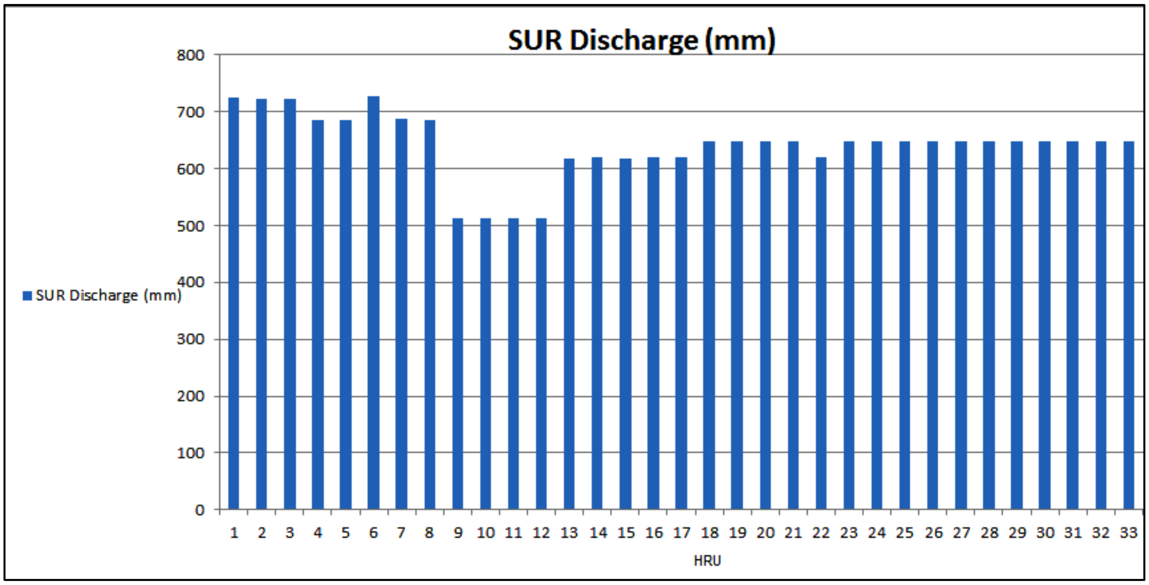

Fig. 6: Surface discharge per HRU

Fig 6 shows the graphical result of surface discharge values of thirty-five HRUs; the maximum value was for HRU 7. Fig 7 shows the graphical result of evapotranspiration values of thirty-five HRUs; the maximum value was for HRU 24.

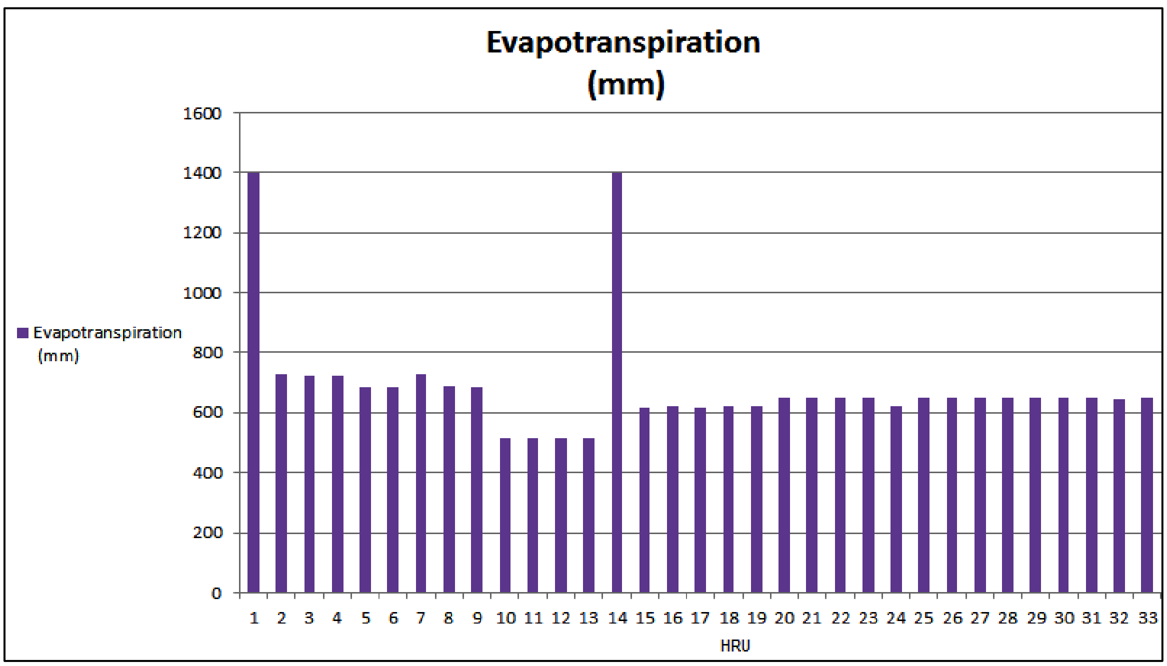

Fig. 7: Evapotranspiration per HRU

6. Conclusion

Ten years of data was used as an input in ArcSWAT for estimating and modelling surface discharge and sediment yield of the watershed. The model concluded that the precipitation of the watershed might be too high (>3,400 m). Surface runoff ratio may be excessive. Average sediment yield is greater than ten metric tonne per ha. This is very high for a basin average. Maximum sediment yield is greater than 50 metric tonne per ha in at least one HRU. The highest value is for HRU-34, sub-basin 28. It was also concluded by the results that average evapotranspiration was 680mm for a year with precipitation of 3595mm for a year and runoff was 2100mm which is more than half of precipitation.

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