CHAPTER 4

SEDIMENT MODELING OF RIVER GANGA BASIN NEAR VARANASI

4.1 INTRODUCTION

The sediment yield of the basin depends upon various factors, including morphometric parameters and metrological characteristics. Moreover, in a basin, different types of sub-watershed contribute to sediment concentration. In this chapter, sediment yield modelling of the river Ganga basin near the Varanasi was done with the help of SWAT analysis. In the following sections, details of the methodology used in this study results obtained, discussion and summary are presented.

4.2 STUDY AREA

The selected study area covers the Varanasi watershed, and it is part of eastern Uttar Pradesh. The river Ganga is one of the largest rivers of this watershed, which flows approximately 35 kilometres. The total area of the Varanasi watershed is 366 square kilometres. The detailed description of the study area for sediment yield modelling is stated in subsection 3.2.1 of chapter 3.

4.3 METHODOLOGY

For the sediment yield modelling, the Ganga river basin near Varanasi (SWAT) analysis was used. SWAT tool was used with the help of ArcSWAT. Figure 4.1 shows the flowchart of the methodology used in this study. SWAT 2012 is the principal tool used in this study to demonstrate the hydrology of the Varanasi watershed. SWAT is a watershed level model. It is a persistent, process-based model that works daily steps and utilizes a command structure for directing overflow and chemical substances through the watershed. As input data DEM, soil map, Land Use Land Cover map and Metrological data were used as input data for SWAT analysis. Soil map and LULC map were used for Hydrological Response Unit (HRU) analysis. .As output runoff, sediment yields and evapotranspiration were obtained. Validation of the model used was done by comparing the result obtained from the model with the result obtained by direct measurement.

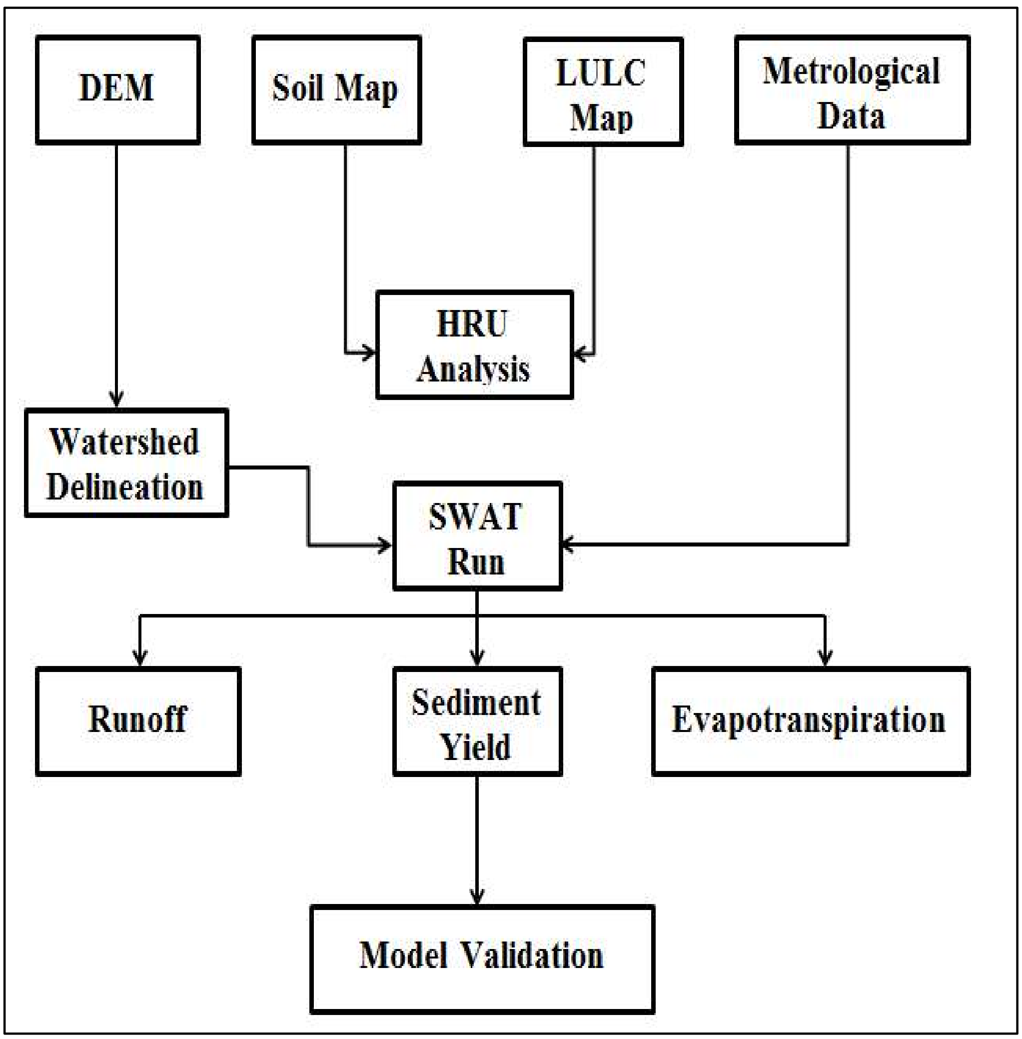

Figure 4.1 Methodology used for sediment analysis

4.4 DATA USED

As mentioned above, input data for modelling of the sediment of river Ganga basin used are: (a) DEM data of basin considered (b) Soil Map/Data (c) LULC map (d) Metrological Data. Details of these data are presented in the following sub-sections.

4.4.1 DEM DATA

The elevation information of the study area was obtained from the Shuttle Radar Topography Mission (SRTM) DEM. The 30 m resolution SRTM- DAM was downloaded from the earthexplorer of the United States Geological Survey (USGS) website. The coordinates of the image lie between 82°51'54.137"E 25°26'26.694"N and 83°13'5.092" E 25°11'15.242" N the detail of DEM given in Table 4.1.

Table 4.1 Details of SRTM- DEM

Sl. No.	Entity Id	Coordinates	Publication Date	Spatial Resolution	File Format
1	SRTM1N25E082V3	25, 82	23/09/2014	30 m	GeoTIFF
2	SRTM1N25E083V3	25, 83	23/09/2014	30 m	GeoTIFF

Two SRTM - DEM is used to cover the whole study area. Both DEM or tiles were mosaicing for creating as one image in ArcGIS. The final prepared DEM had shown in Figure 4.1. The geospatial technique is used to extract the watershed data. The Varanasi watershed was divided into 27 subwatershed shown in subsection 3.2.1 of chapter 3. For this, the ArcGIS tool was used for the creation of the subwatershed.

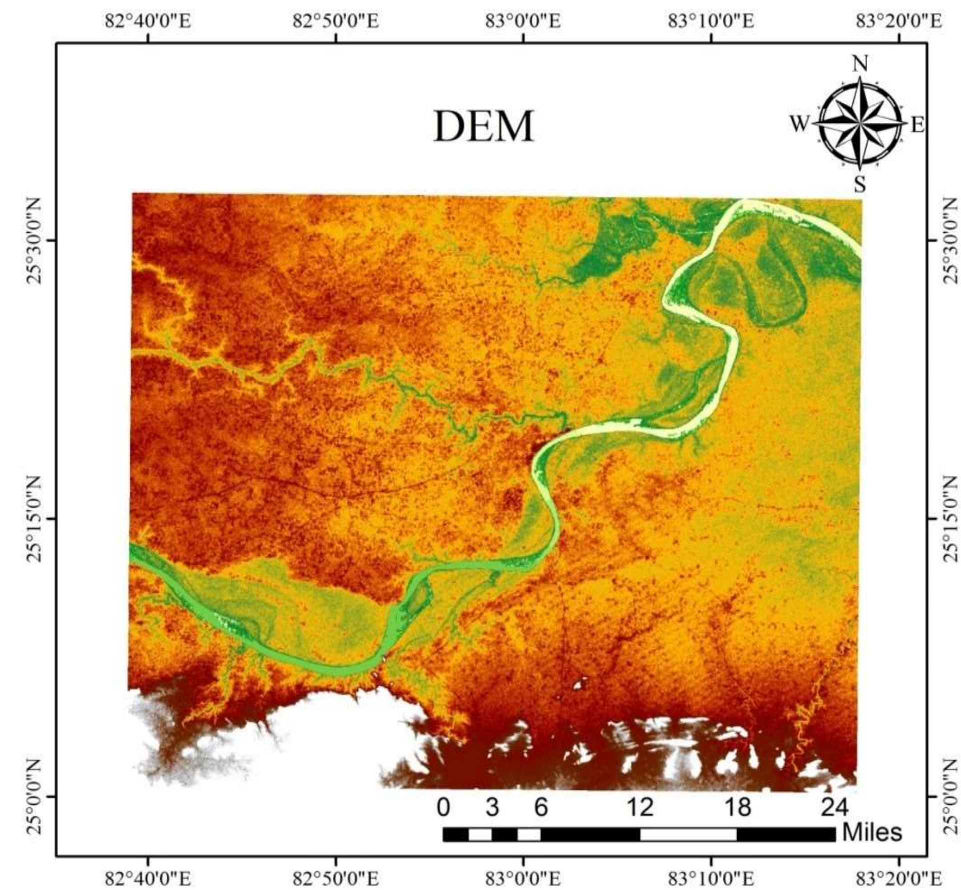

Figure 4.3 DEM of the study area

4.4.2 SOIL MAP/DATA

The soil map of the study area used in this study is given in Figure 4.3. The soil data were obtained from the data provided by the National Bureau of Soil Survey (NBSS) and Land Utilization Planning (LUP). The soil map shows that two types of soils were present in the study area. The first type of soil is clay/silt, which covers most of the watershed regions. At the same time, the second type of soil is sand which covers the convex side of the river primarily. The deposition of sediments formed such a region. For HRU analysis user soil database describing each soil type is presented in Table 4.2.

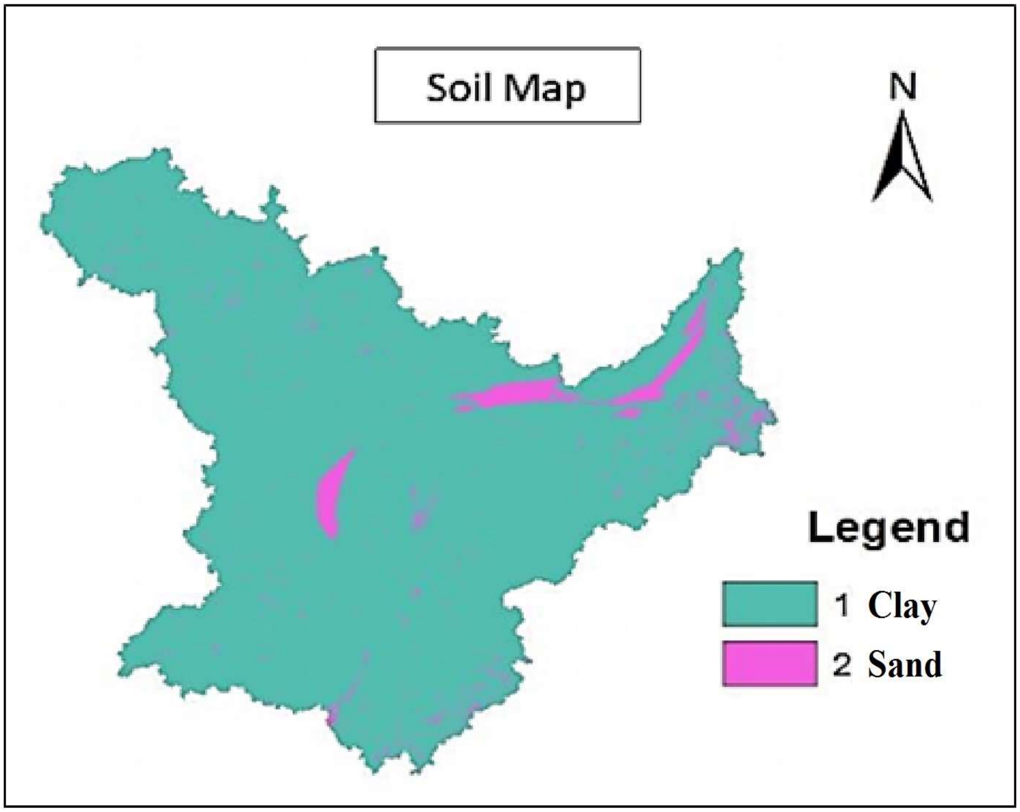

Figure 4.3 Soil map of the study area

Table: 4.2 Details of the properties of the soil covering watershed

SNAM (***Soil Name***)	**Soil 1 Rc1-2a-194**	**Soil 2 Xh14-ab-303**
HYDGRP(Hydrological soil group)	D	C
TEXTURE	L	SL
SOL_Z1(depth of soli layer 1 in mm)	300	300
SOL_BD1(Bulk density of layer 1 in g/cm^3)	1.5079	1.5952
SOL_AWC1(available water capacity of layer 1)	0.1441	0.0893
SOL_K1(hydraulic conductivity in mm/hr of layer)	4.1604	30.1535
SOL_CBN1(carbon content in layer 1(% soil weight in m^3 metric ton cm))	0.6	0.6

CLAY1(percentage of clay in layer 1)	28	13
SILT1(percentage of silt in layer 1)	42	23
SAND1(percentage of sand in layer 1)	30	64
SOL_ALB1(soil albedo in layer 1)	0.3971	0.3971
USLE_K1(USLE erodibility factor in layer 1)	0.1719	0.1687
SOL_BD2(Bulk density of layer 2)	1.535	1.6026
SOL_AWC2(available water capacity of layer 2)	0.1202	0.0914
SOL_K2(hydraulic conductivity in mm/hr of layer 2)	3.6147	21.7927
SOL_CB N2(carbon content in layer 2)	0.5	0.5
CLAY2(percentage of clay in layer 2)	31	16
SILT2(percentage of silt in layer 2)	26	22
SAND2(percentage of sand in layer 2)	43	62
SOL_ALB2(soil albedo in layer 2)	0.4254	0.4254
USLE_K2(USLE erodibility factor in layer 2)	0.1561	0.1658

4.4.3 LAND USE LAND COVER MAP (LULC)

Land Use Land Cover (LULC) map is prepared with the help of the DEM. ERDAS imagine tool was used to process the satellite imagery. LULC map used in this study is presented in Figure 4.4. In the study area, six different types of land cover were found. Agriculture land, Barren land, cultivated land, forest land, urban land and water surface covers the area considered under this study. Most of the part of the watershed covers the urban area with minimal agricultural land available for farming. The forest area is also very less in the city. The middle part has the river Ganga and plays an essential role in fulfilling water requirement.

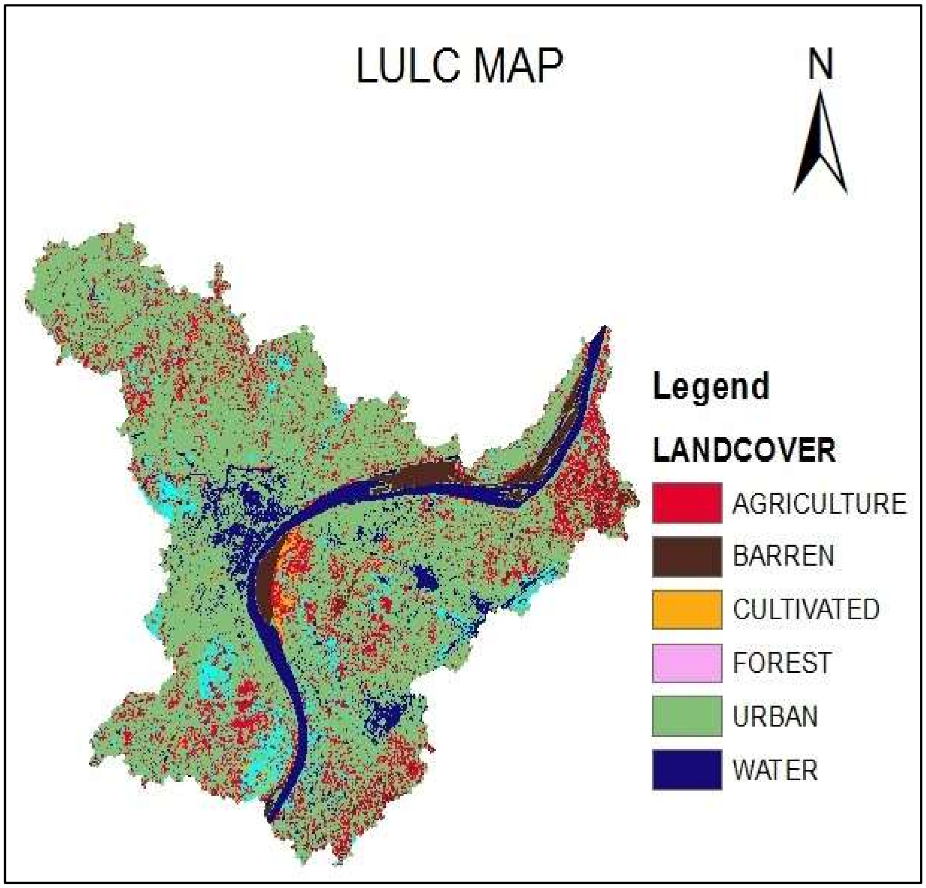

Figure 4.4 LULC map of the study area

4.4.4 METROLOGICAL DATA

Daily precipitation, solar radiation data, temperature data, humidity data, wind direction data of 07 years were used in this present study. All metrological data were acquired from Indian Meteorological Department (IMD). The metrological data is essential for the focused work, and each data have played a specific role in the input data section. The input data selection solely depends on the model input requirement. More available data will give a more precise output, so daily metrological data were used for the present study.

4.5 DATA PROCESSING

Preparation of the LULC map, Hydrological Response Units (HRU) analysis, and SWAT analysis were done in this study. The details of the processes are discussed in the following sub-sections.

4.5.1 PREPARATION OF LULC MAP

The LULC map was prepared with the help of supervised classification using the 'ERDAS Imagine Tool. The multiple bands in the electromagnetic spectrum form a satellite image. The image form by multiple bands gives only spectral information. But for the LULC map, the spectral data is required to be converted into LULC information class by including image classification. In image classification, a particular pixel indicates a specific land type like; water or forest or any other. The classification was done based on the spectrum of the pixel. To processed satellite image of large pixel size, automated classification is required. This is generally done in two ways first one is supervised digital classification, while the second one is unsupervised digital classification. In supervised expert prepare a signature dataset of specific land cover. Then computational facility or software uses that dataset to create a spectral class. In unsupervised digital classification, the number of class required is specified by the user first. Then the software classifies the image automatically. In this study, the 'ERDAS Imagine Tool' has used supervised classification for preparing the LULC map shown in Figure 4.4.

4.5.2 HRU ANALYSIS

Watershed and HRU delineation was done with the help of the DEM. The watershed divided into 27 sub-watershed, and HRU divided into 33 HRU. All 27 sub-watershed, along with the streams, is given in Figure 4.5. The division of 33 HRU is based on several parameters, such as the LU&LC map and soil map. All input data were prepared in updated in the SWAT database for further analysis and simulation work. It is created to foresee land management, anthropogenic activities, climate change, global warming, and changing soil type. ArcSWAT is the most recent accessible rendition, which is utilized as an interface amongst ArcGIS and SWAT. In this study, SWAT 2012 is used. Input required was the DEM, LULC map data in ArcGIS 10.1.

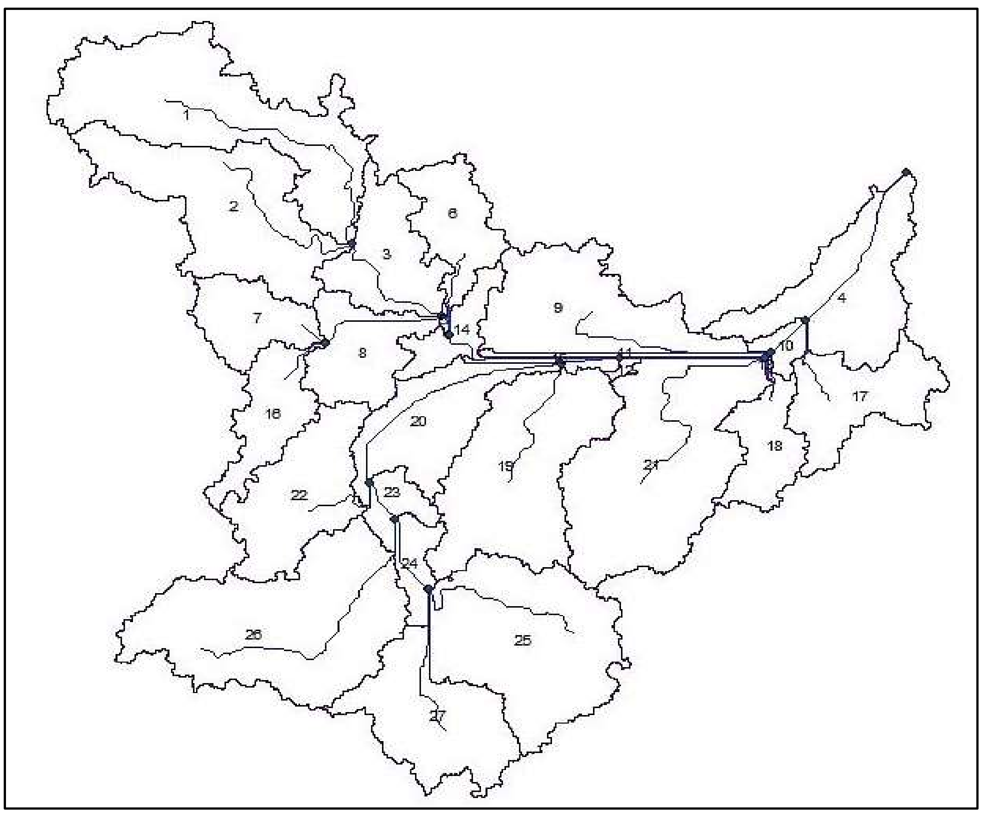

Figure 4.5 Twenty Seven Sub-watersheds

4.5.3 SWAT ANALYSIS

For the analysis of sediment yield, the SWAT tool is used for the study. It estimates the hydrological and metrological parameter such as rainfall, surface discharge, lateral discharge, groundwater discharge, water stored in the soil profile, evapotranspiration, potential evapotranspiration, water yield and sediment yield. The ArcSWAT is one of extension of ArcGIS, which is used for the study and some of the hydrological equation is used such as SCS-CN method, water budget equation of watershed and universal soil loss equation.

The following equation related to the SWAT analysis for water budgeting:

$$R=S+ET+\Delta S \tag{4.1}$$

R is rainfall, S is streamflow, ET is evapotranspiration, and ΔS changes of soil storage.

Equation 4.1 is based upon the conservation of mass for a closed system. The water is the primary input for the system. It is distributed in various forms on earth like runoff, evaporation, surface runoff, evapotranspiration, and stored in the groundwater table.

There are two most widely used methods to calculate the runoff from a specified rainfall: Soil Conservation Service Curve Number (SCS-CN) and the second is Universal Soil Loss Equation (USLE). The SCS-CN define by Equation 4.2. It is estimated the approx. amount of runoff and the general equation for the SCS-CN method is given below:

$$Q = \frac{(R-Ia)^2}{(R-Ia)} + S \tag{4.2}$$

Q = runoff, R = rainfall, S = maximum potential retention after Q begins and initial abstractions.

$$I_a = 0.2S \tag{4.3}$$

$$Q = \frac{(R-0.2S)^2}{(R+0.8S)} \tag{4.4}$$

$$S = \frac{1000}{C_N} - 10 \tag{4.5}$$

The USLE method is used for the average estimation o runoff for particular rainfall. It can also estimate soil average annual soil loss due to sheet erosion and rill erosion. Equation 4.6 define the USLE method, and It is given as

$$A = R \times K \times L \times S \times C \times P \tag{4.6}$$

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.

Sediment transport comprises of two parts scenes and channels. From the scene, segment SWAT predicts the residue yield inside each hydrological response unit utilizing Modified USLE (Williams 1995).

$$Specific\ yield\ (S_y) = 11.8\ (Q_s q_p A_{hru})^{0.56} KCP(LS) C_{FRG} \tag{4.7}$$

where, Sediment yield (S_y) on a given day (metric tons), Q_s = surface runoff volume (mm /ha), q_p = the peak runoff rate (m^3/s), A_{hru} = area of HRU (ha), K = soil erodibility factor, C = cover factor, P = support practice factor, LS = Topographic factor, CFRG = Coarse fragment factor.

As prescribed by numerous specialists, preceding running the SWAT reproductions the hydrologic and meteorological datasets were isolated into two sub-datasets: one for SWAT calibration (2010 to 2013) and one for SWAT validation (2014 to 2016). The subsequent stage in the alignment and approval process was to decide the most delicate parameters for analysis. Affectability investigation determines the rate of progress in the display, yield concerning changes in demonstrating input parameters (Arnold et al. 2012). In the current research, SWAT-CUP (Abbaspour 2007) (alignment and vulnerability programs) was utilized for the affectability examination, adjustment and vulnerability investigation of the model runs. A SUFI-2 vulnerability examination routine was utilized.

4.5.4 SUFI -2 MODEL

There is a various hydrological model developed for accurate estimation, but due to significant uncertainties, there is need of research in this area. Researchers try various uncertainties analysis to improve their watershed models. Some estimation techniques are commonly used in GLUE, Sequential Uncertainty Fitting SUFI-2 and solution parameters (Parasol). Beven and Binley (1992) worked on GLUE for future distribution model, Abbaspour (2007) contributed in the user manual for SWAT-CUP for SIFI-2 and Alamirew (2006) used Parasol for modelling of basin soil erosion. All following method of calibration is available in the SWAT-CUP called SWAT calibration uncertainty program. In our work, SUFI-2 is used for the calibration and validation of the SWAT model. There are three measures used for the quality assessment of calibration and sensitivity analysis. The first measurement variable is the percentage of data excluded by the 95 per cent prediction uncertainty (95PPU), the second is Nash–Sutcliffe efficiency (NSE) plotted between best estimation and observed. The third is the coefficient of determination (R^2).

The formula for the coefficient of determination (R^2):

$$\text{Coefficient of determination } (R^2) = \frac{\sum(\hat{S} - L)^2}{\sum(S - \bar{S})^2} \tag{4.8}$$

$$\text{Nash–Sutcliffe efficiency (NSE)} = 1 - \frac{\sum(S - L)^2}{\sum(S - \bar{S})^2} \tag{4.9}$$

where, S = observed data, $\bar{S}$ = Mean of observed data, $\hat{S}$ = predicted data and L= Computed data.

4.6 RESULTS AND DISCUSSION

4.6.1 MODEL APPLICATION

The calibration and validation of the model play a significant role in the model simulation process than receive quality results from the model. Therefore, the model was calibrated and validated with the use of monthly discharge data. The total period of data from 2010 to 2016 was available, which is seven years of data.

There is a need for data selection for calibration and validation—the segregation of data based on data availability for the study area. Here, seven-year data is divided into two parts; the first part is used for calibration, selected from 2010 to 2013. The second part of the data is used for validation, which is chosen from 2014 to 2016. The year 2013 and year 2016 receive a very high discharge and rainfall compared to other year's data.

4.6.2 MODEL CALIBRATION

The monthly flow data were used for the calibration modelling. The four-year data were used for the calibration. Here maximum monthly data were used for calibration because the more input data creates a more accurate calibration model. SUFI-2 was used for the calibration in SWAT-CUP. It is a program for the calibration and validation of the given SWAT model. The SWAT-CUP is lined with various algorithms, Such as SUFI-2, GLUE, etc., for accurate model calibration. Here SUFI-2 were used for the model calibration and validation.

The performance is measured with the help of coefficient of determination, percent prediction uncertainty (95PPU) and Nash–Sutcliffe efficiency, as shown in Figure 4.6. The calibration result is estimated using SUFI-2 for monthly flow, where percent prediction uncertainty, Nash–Sutcliffe efficiency and coefficient of determination are 0.65, 0.76 and 0.75, respectively.

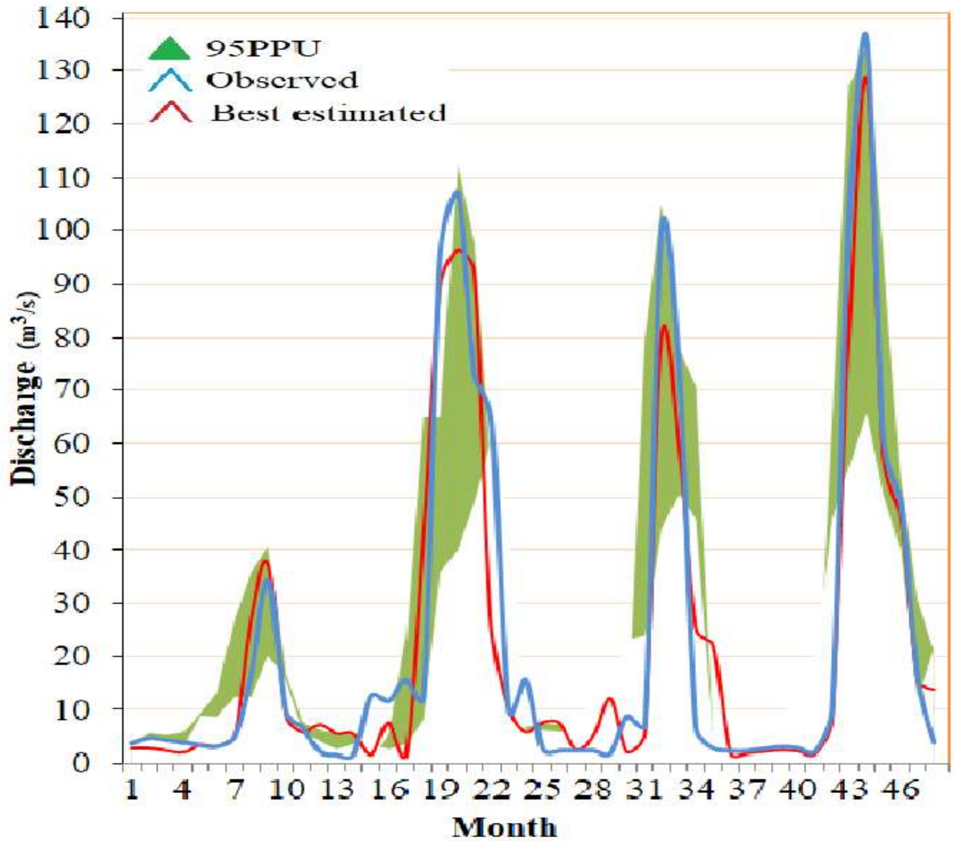

Figure 4.6 Monthly discharge calibration

4.6.3 MODEL VALIDATION

The SWAT model validation was used from three years of monthly data(36 months) as shown in Figure 4.7. The validation data were different from the calibration period. Hence, the various data set selection to give a more accurate estimation. Moriasi et al. (2007) suggested the selection of monthly data set for the calibration and validation. The validation result is estimated using SUFI-2 for monthly flow, where percept prediction uncertainty, Nash–Sutcliffe efficiency and coefficient of determination are 0.61, 0.72 and 0.74, respectively.

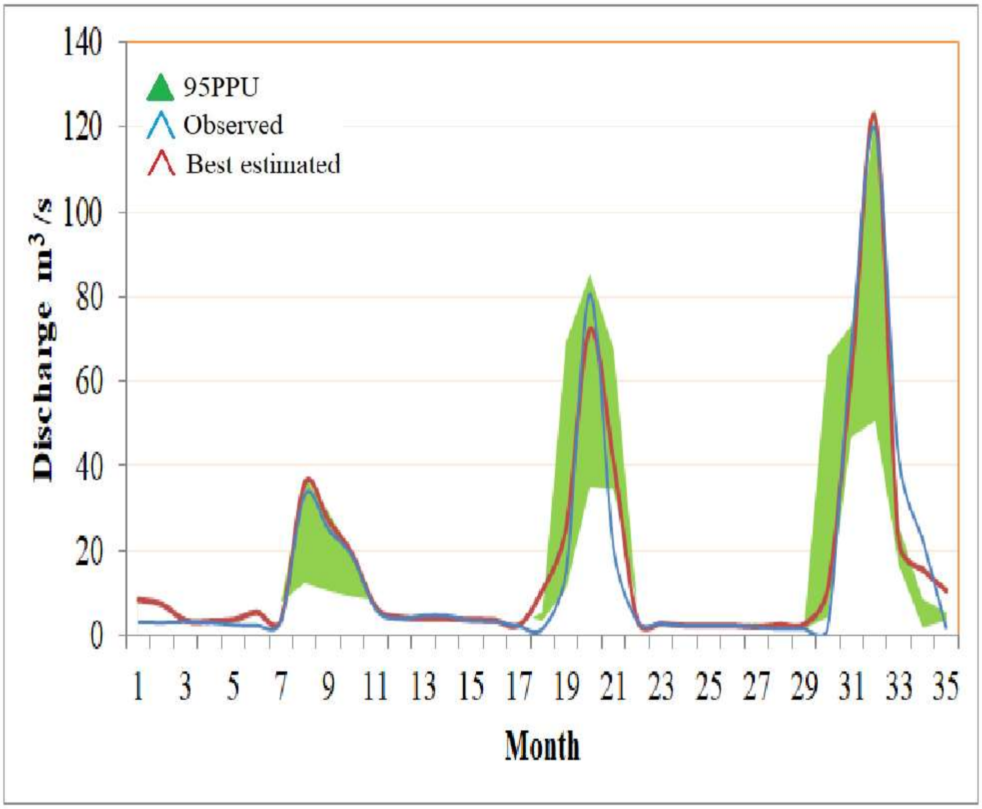

Figure 4.7 Monthly discharge Validation

4.6.4 SWAT RESULTS

The SWAT model used 7 years of daily data for the analysis. The results of this study showed that the average annual precipitation of the basin is 993.5mm, surface runoff Q is 385.99 mm, Lateral Soil Q is 11.95mm, Groundwater (Shallow Aquifer) Q is 244.34mm, water stored in soil profile 219.44 mm, evapotranspiration is 284 mm, potential evapotranspiration 513.54 mm, water yield 654.56 mm and sediment yield is 12.31 t/ha as shown in table 4.2. It is clear from the data that more than half of the annual precipitation of water is lost through runoff and evapotranspiration. The urban area covers the maximum part of the basin area. Therefore, the runoff is very high in that area.

It is clear from table 4.3 that sedimentation is increasing year by year in this watershed. Figure 4.10 shows the sediment yield graph for all the HRU, and HRU 22 has the highest Sediment yield value.

Table 4.3 Swat Results

Year	Rainfall (*mm*)	SUR Q (*mm*)	Lateral Q (*mm*)	GW Q (*mm*)	WSSP (*mm*)	ET (*mm*)	PET (*mm*)	W Y (*mm*)	SED Y (*t/ha*)
2010	560.3	144.15	7.76	73.04	223.71	240.56	474.44	227.41	7.19
2011	1026.6	431.73	11.88	165.95	218.42	357.15	670.98	617.19	15.43
2012	772.4	213.28	11.77	273.17	219.27	234.97	429.86	511.63	2.94
2013	1006.2	348.42	13.22	301.73	223.09	269.55	444.85	678.88	17.53
2014	960.7	356.12	11.43	256.07	225.52	284.85	460.49	638.82	3.98
2015	1184	573.7	11.13	248.81	221.35	286.78	490.31	847.57	11.24
2016	1444	634.53	16.47	391.59	204.77	314.1	623.85	1060.43	27.86

Note: SUR Q: Surface water runoff, GW Q: Groundwater discharge, WSSP: Water stored in soil profile, ET: Evapotranspiration, PET: Potential evapotranspiration, WY: Water yield, SED Y: Sediment yield

The comparison of observed and predicted data of evapotranspiration is shown in figure 4.8. The observed data were collected from IMD and predicted data was collected from SWAT results. The predicted SWAT result of evapotranspiration is similar to the observed field data. Both data are very much identical at maximum point except two-point. The comparison is giving a promising result. Based on the comparison observed and predicted data of evapotranspiration, the SWAT result was giving good results.

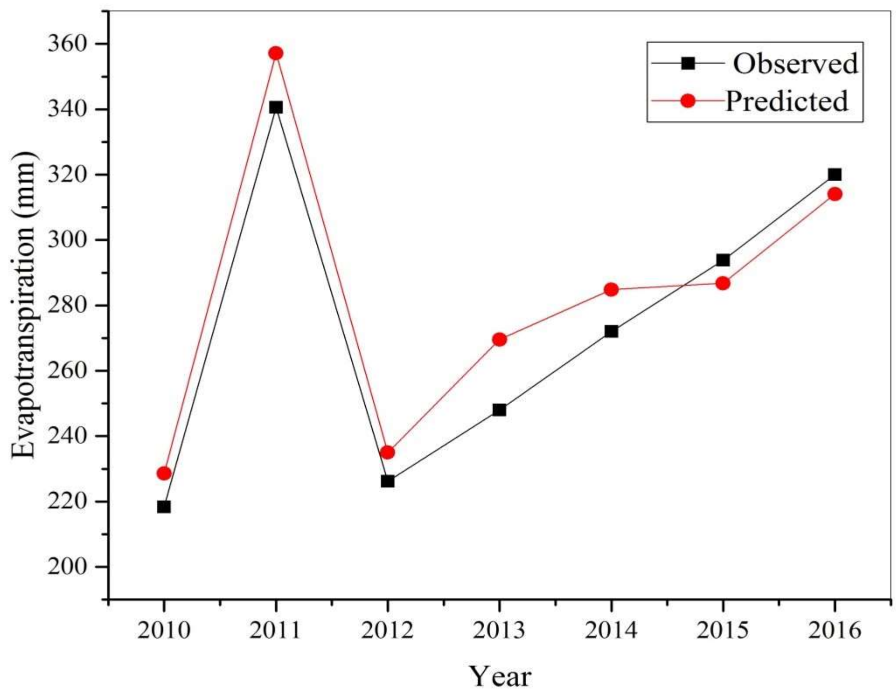

Figure 4.8 Comparision of observed and predicted evapotranspiration

Figure 4.9 shows the graphical result of sediment yield values of thirty-three HRUs; the maximum value was for HRU 22 and the least value obtain for HRU 12.

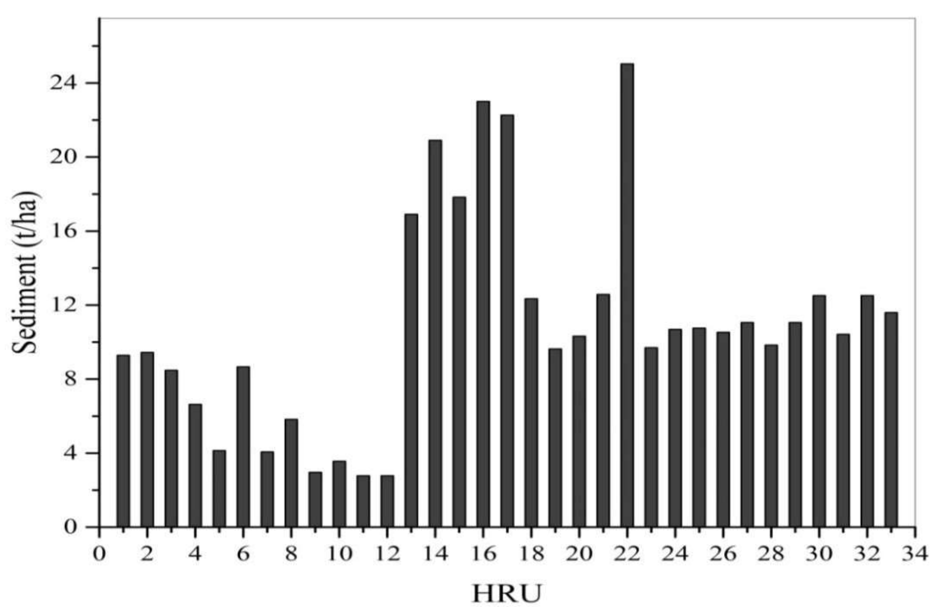

Figure 4.9 Sediment yield per HRU

Figure 4.10 shows the graphical result of evapotranspiration values of thirty-three HRUs; the maximum value was for HRU 14. The minimum value for evapotranspiration is observed for HRU 12. Thus, the maximum annual sediment yield is 27.86 t/ha for 2016, where the highest rainfall is 1444 mm.

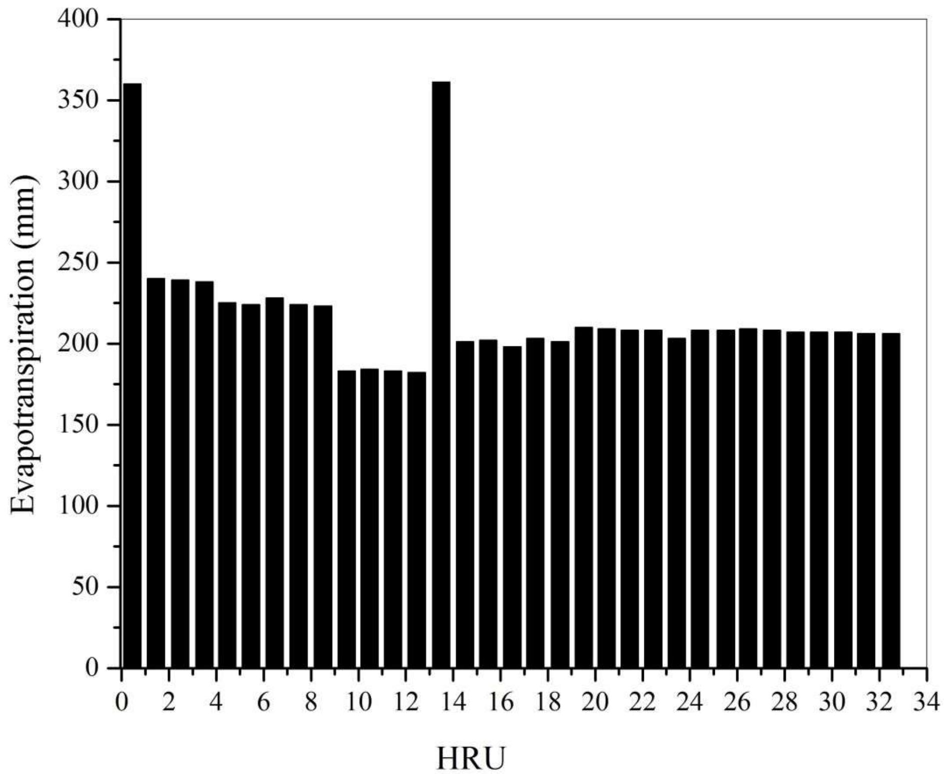

Figure 4.10 Evapotranspiration per HRU

4.7 CONCLUSION

The Varanasi watershed's soil and water problems are critical because of the growing population and climate change. The ever increasing population change the LULC pattern of Varanasi. Sustainable uses resources are essential for various aspects. For this, an appropriate model is required in this area for surface runoff and sediment yield modelling. In this Chapter, SWAT is used to model sediment yield processes of the Varanasi watershed in the Ganga basin. Seven years of daily meteorological data, soil data, DEM, satellite imagery are collected for the model input. The watershed was divided into 27 sub-basin for analysis and modelling.

The Sufi-2 algorithms were used for calibration and validation. The data was divided into two data set. Total four-year data was used for calibration, and three-year data used for validation of the model. Performance of calibration and validation were evaluated based upon percent prediction uncertainty, Nash–Sutcliffe efficiency and coefficient of determination.

The results revealed that more than half of the annual precipitation water is lost in evapotranspiration and runoff. It is also observed that the runoff is predominant in the basins considered. It is observed that the maximum annual sediment yield is 27.86 t/ha for 2016, where the highest rainfall is 1444 mm. The model revealed that the SWAT model is capable of being used in hydrological and sediment yield modelling.