# CHAPTER 6. UTILIZING SOIL AND WATER ASSESSMENT TOOL (SWAT) FOR HYDROLOGICAL MODELING

## 6.1 Introduction

Water & soil are primary resources for sustainable economic and social development. Over the years, because of the anthropogenic 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. The need of the hour is to find ways to conserve and manage these resources such that future generation can also make use of them.

During the past few years, many 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 (Young et al., 1987, Tripathi et al., 2003). For example Measurement and modeling of soil erosion and sediment yields in a vast cultivated land of south Brazil was done using WATEM and SEDEM model (Didone et al., 2017). WEPP cannot perform better than MUSLE for soil loss estimation; he used three methods USLE-M, RUSLE-2, and WEPP for erosion management (Yesuf et al., 2015). In Chinese Loss Plateau soil erosion estimation was done using three methods Si Model, WEPP, MMF and then the results were compared (Li et al., 2017). WEPP is the model which can be successfully used for both runoff and sediment estimation using GIS and remote sensing techniques (Pandey et al., 2008). SCS-CN method is the most widely used method for Runoff estimation and watershed management (Shivhare et al., 2018). Unit Sediment Graph is the better process than Modified USLE and WEPP when Climate change factor is considered (Chandrashekar et al., 2015). Prediction of soil erosion is more straightforward using WEPP along with GIS techniques (Mahmoodabadi & Cerdà 2013).

Among these models, the physically based circulated display SWAT is entrenched for dissecting the effects of land management practices on water, silt, and complex watersheds. SWAT is a very widely used model for sediment yield modeling (Jeong et al., 2012). SWAT is used for watershed management to enhance water quality requirements (Mittelstet et al., 2016). Sediment yield estimation can be more easily done when SWAT is integrated with GIS using Arc SWAT ( Kinnel 2018) studying all these models; it was concluded that SWAT is the most appropriate model to be used in the present study area for modeling. As the SWAT is the time persistent model and it can simulate surface discharge, soil erosion, and also the nutrient content of the soil (Fukunaga et al., 2015). SWAT and Sediment filtration models help in control sedimentation during small storms. SWAT has been effectively utilized by specialists around the globe for appropriated hydrologic modeling and management of water assets in watersheds with the different atmosphere and territory attributes.

The SWAT model is a physically based & continuous model developed by the USDA Agricultural Research Service (ARS) (Arnold & Allen 1996). 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. (Prabhanjan et al., 2014) integrated the SWAT model with geospatial techniques like Remote Sensing & GIS for modeling runoff and sediment yield for Khadakohol & Harsul watersheds in Maharashtra, India.

In the present chapter, The SWAT model required a digital elevation model (DEM), a land use/land cover (LULC) map, and a soil map as inputs for watershed delineation and hydrological response unit (HRU) analysis. Daily meteorological data from the four stations of Balia, Varanasi, Babatpur, and Gazipur were utilized from 1996 to 2015. The primary target of this examination was to delineate the watersheds, divide the study area into sub-watersheds, determine the number of streams, and estimate their order, and then to establish information regarding the outlet points and reservoirs available in the watershed in order to accurately divide it into HRUs having similar but unique land types, soil types, and elevation properties. These units permit simpler modeling. Finally, after providing the meteorological data, the SWAT was run to estimate runoff, sediment yield, and evapotranspiration for each HRU and sub-watershed. The primary goals of this chapter are: to assess the execution of the SWAT in Varanasi watershed and to demonstrate and survey the practicality of utilizing SWAT for hydrologic modeling in this region.

## 6.2 Data

Elevation data, LULC data, soil data, and daily meteorological data were the prerequisites for the present modeling. The Shuttle Radar Topology Mission (SRTM) DEM, was used for elevation data. For the LULC map, image classification was performed using satellite imagery from Landsat 8. For meteorological input, data for the daily rainfall, temperature, solar radiation, and pressure for 20 years were used.

## 6.3 Data Preprocessing

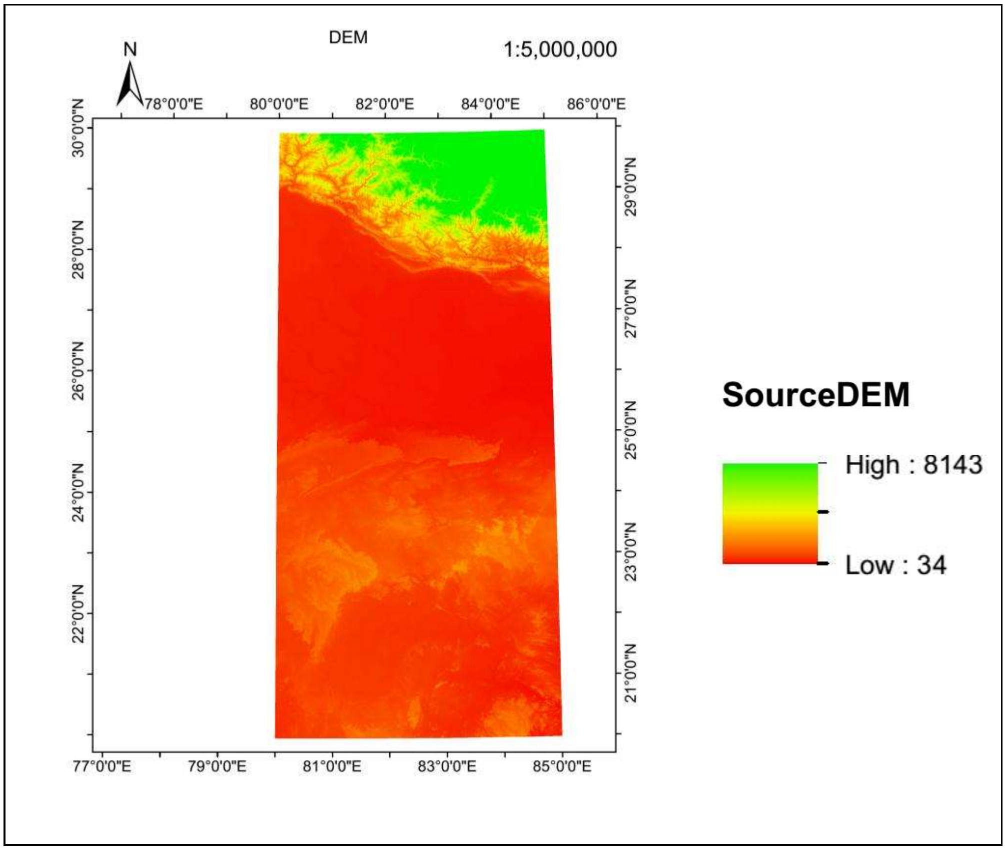


Figure 6.1 DEM

### 6.3.1 Spatial Data

For spatial data, Landsat-8 Thematic Mapper (TM) multispectral images of Nov 2015 and 2016 were procured from earth explorer USGS with row and path of the images are (141,42), (141,43) and (141,42) for Land use land cover mapping. Shuttle radar thematic mapper (SRTM) Digital elevation model (DEM) of resolution 30 m covering an area from 82°1'52.439"E 26°2'7.842"N to 83°55'10.63"E 24°22'53.034"N was procured from USGS Earth Explorer website for watershed delineation. Soil data was collected from the National Bureau of soil survey (NBSS) also some of the soil data was estimated by the lab experiments of soil samples. The observed data of the sediment yield for Varanasi station to be used for calibration was procured from Central Water Commission Varanasi.

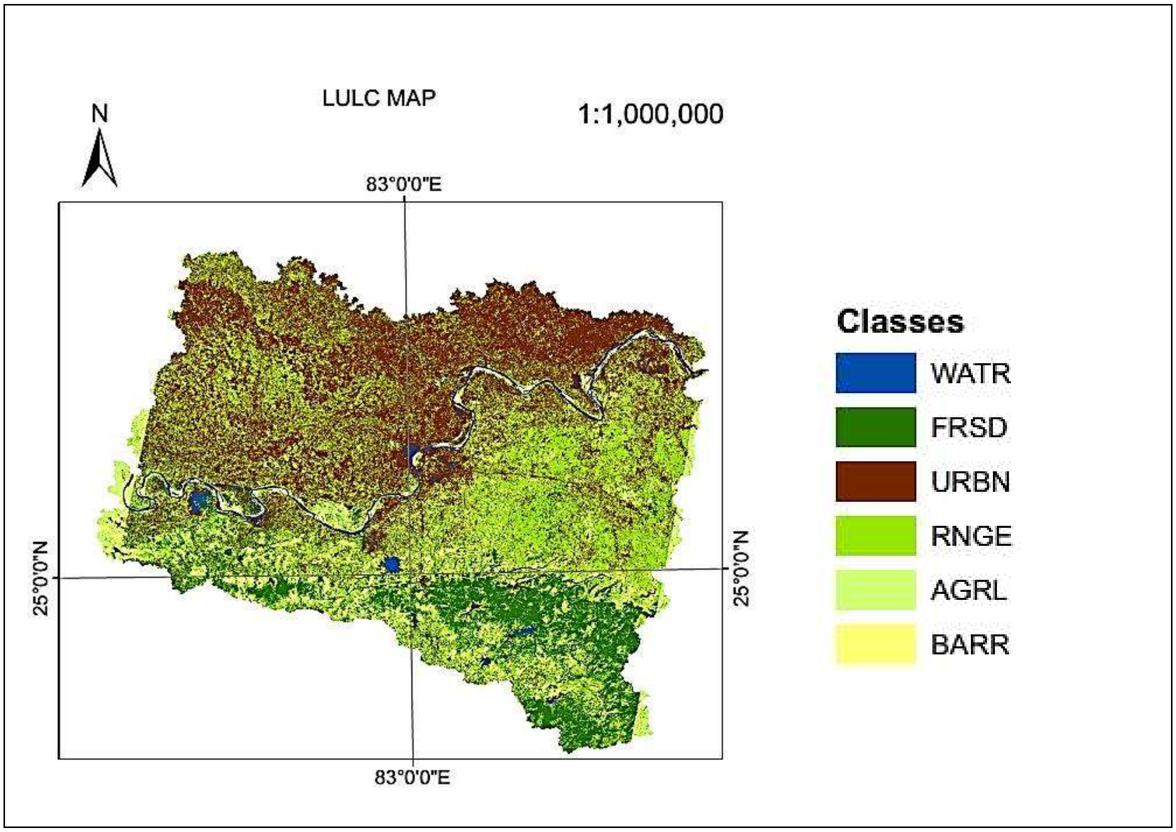


Figure 6.2 LULC map of the study area.

### 6.3.2 Satellite Data

For using DEMs in a project, it is important to check the DEMs for null values. If the null values are present image processing needed to be done for removing the null values. In this project Fill function of ArcGIS 10 was used to remove the null values from DEMs. After correcting the DEMs, all the DEMs were Mosaicked using image processing tool Erdas Imagine. The mosaicked DEM is shown in Figure 6.1. Satellite images were used for creating the Land Use/ Land Cover (LULC) map. For this Landsat 8 images were stacked first using image processing, then the mosaicking was done and as the final step supervised image classification was done using image interpretation tool. The image was classified into six different classes they are BARR (Barren land), URBN (Urban area), FRSD (Forest land), AGRL (Agricultural land), WATR(Water Body), and RNGR (Rangeland). Figure 6.2 shows the LULC map of the study area.

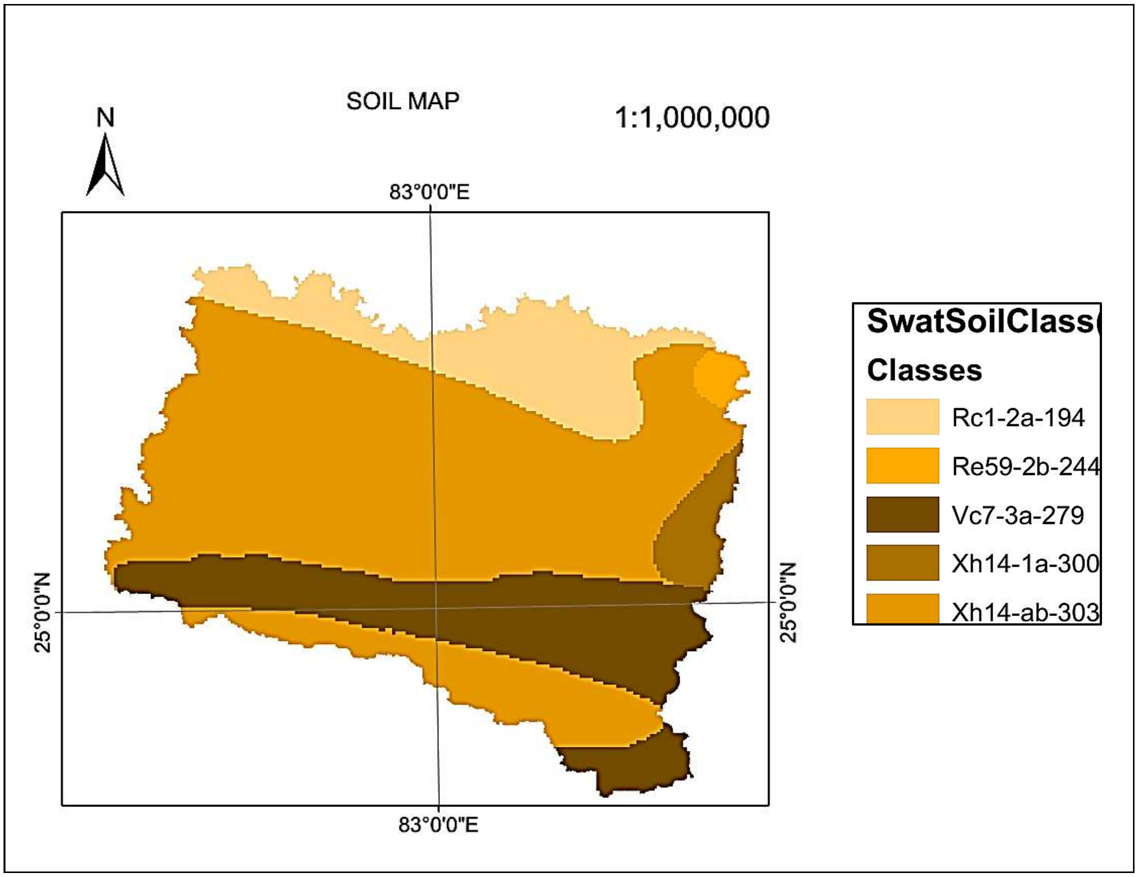


Figure 6.3 Soil map

### 6.3.3 Soil Data

The soil data was procured from NBSS. And the data was validated by lab testing. For this, the land was divided into two soil layer with a depth of 30cms each. The samples were tested, and the soil map was prepared to divide the watershed into 5 types of soil classes shown in Figure 6.3. The details of these classes are given in Table 6.1.

Table 6.1 Details of Soil Classes

| | Soil Properties | Soil classes | | | | |
|---|---|---|---|---|---|---|
| | | **Rc1-2a-194** | **Re59-2b-244** | **Vc7-3a-279** | **Xh14-1a-300** | **Xh14-ab-303** |
| General | S5ID | IND194 | IND244 | IND279 | IND300 | IND303 |
| | HYDGRP (hydrological soil group) [a] | D | C | D | C | C |
| | TEXTURE [b] | L | L | CL | SCL | SL |
| Layer 1 | SOL_Z1 (depth of soil in mm) | 300 | 300 | 300 | 300 | 300 |
| | SOL_BD1 (bulk density in gm/ml) | 1.51 | 1.56 | 1.50 | 1.58 | 1.60 |
| | SOL_AWC1 (available water capacity in mm $H_2O$ / mm Soil) | 0.14 | 0.12 | 0.13 | 0.10 | 0.09 |
| | SOL_K1 (hydraulic conductivity in $mm \cdot h^{-1}$) | 4.16 | 9.78 | 4.06 | 12.98 | 30.15 |
| | SOL_CBN1 (carbon content in %soil weight) | 0.6 | 0.8 | 0.8 | 0.7 | 0.6 |
| | CLAY1 (percentage of clay) | 28% | 22% | 30% | 21% | 13% |
| | SILT1 (percentage of silt) | 43% | 31% | 34% | 21% | 23% |
| | SAND1 (percentage of sand) | 30% | 47% | 36% | 58% | 64% |
| | SOL_ALB1 (soil albedo) [c] | 0.40 | 0.35 | 0.35 | 0.37 | 0.40 |
| | USLE_K1 (USLE erodibility factor) | 0.17 | 0.16 | 0.16 | 0.16 | 0.17 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Layer 2 | SOL_BD2 (bulk density of layer 2) | 1.54 | 1.56 | 1.48 | 1.60 | 1.60 |
| | SOL_AWC2 (available water capacity of layer 2) | 0.12 | 0.12 | 0.14 | 0.10 | 0.09 |
| | SOL_K2 (hydraulic conductivity in $mm \cdot h^{-1}$ of layer 2) | 3.61 | 10.37 | 2.42 | 12.83 | 21.79 |
| | SOL_CBN2 (carbon content in layer 2) | 0.5 | 0.9 | 0.4 | 0.5 | 0.5 |
| | CLAY2 (percentage of clay in layer 2) | 31% | 22% | 34% | 21% | 16% |
| | SILT2 (percentage of silt in layer 2) | 26% | 28% | 36% | 20% | 22% |
| | SAND2 (percentage of sand in layer 2) | 43% | 49% | 29% | 59% | 62% |
| | SOL_ALB2 (soil albedo in layer 2) | 0.43 | 0.32 | 0.46 | 0.43 | 0.43 |
| | USLE_K2 (USLE erodibility factor in layer 2) | 0.16 | 0.16 | 0.16 | 0.16 | 0.17 |

### 6.3.4 Temporal Data

Daily weather data from 1996 – 2015 was procured from Indian meteorological department. The data were collected for 5 stations namely Varanasi, Mirzapur, Babatpur, Balia, and Gazipur. The consistency of the data was checked using a double mass curve method.

## 6.4 Methodology Used

Figure 6.4 shows the flowchart of the methodology used in this study. SWAT 2012 is the key tool used in this study to demonstrate the hydrology of the watershed. SWAT is a watershed level model. It is a time persistent, process-based model that works on day by day steps and utilizes a command structure for directing overflow and chemical substances through the watershed.

The watershed is defined to include both the catchment and the drainage channel within a single morphometric divide. It is a naturally occurring hydrologic unit covered by natural boundaries and characterized by similar conditions like physical characteristics, the topology of the land surface, and climatic conditions. Watershed delineation implies the drawing of lines on a map to indicate a watershed's limits. These are commonly drawn on maps utilizing data from DEM or contour maps.

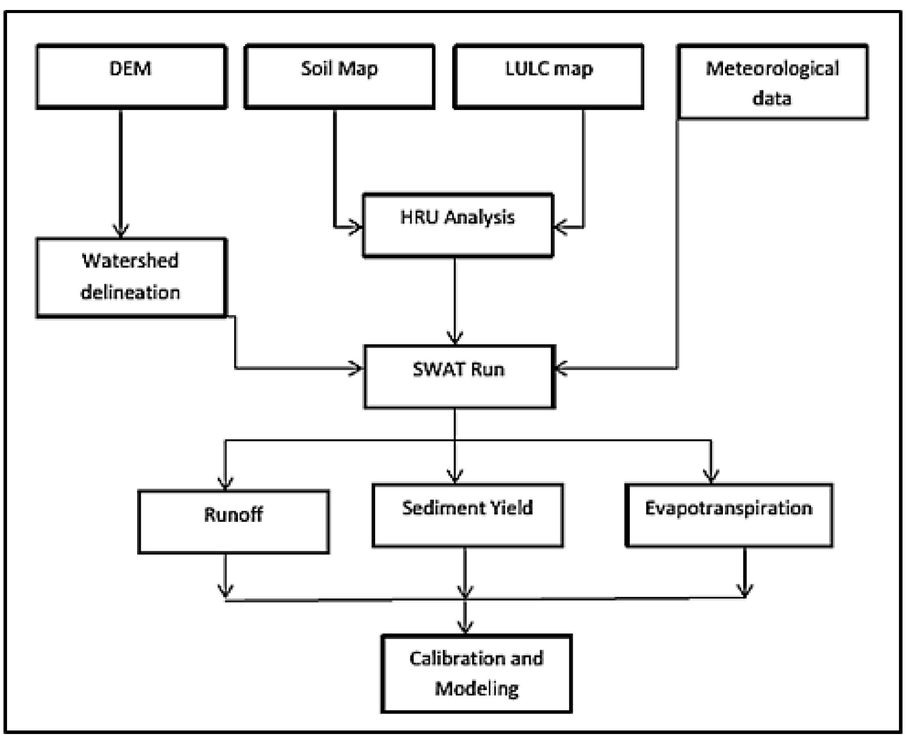


Figure 6.4: Methodology

Watershed delineation is the first step of SWAT modeling. DEM is used as the input in this step. Along with the slope of the watershed, the streams and outlet points are generated. According to the outlet points selected by the researcher, the watershed is delineated. The user can also provide data related to the reservoir and predefined streams as input. In this study, the watershed is delineated by dividing the watershed into 46 sub-watersheds. Figure 6.5 shows the delineated watershed, streams, and monitoring points of the study area. The next step is the HRU analysis. In HRU analysis, the watershed is divided into units having similar but unique land types, soil types, and elevation properties. In this step, using the soil map, user soil table, LULC map, and slope map of the study area, the watershed was divided into 760 HRUs. In the next step, the climate database is provided to the model. Finally, the SWAT model was run to yield the runoff, evapotranspiration, and sediment yields of each sub-watershed and HRU for 20 years.

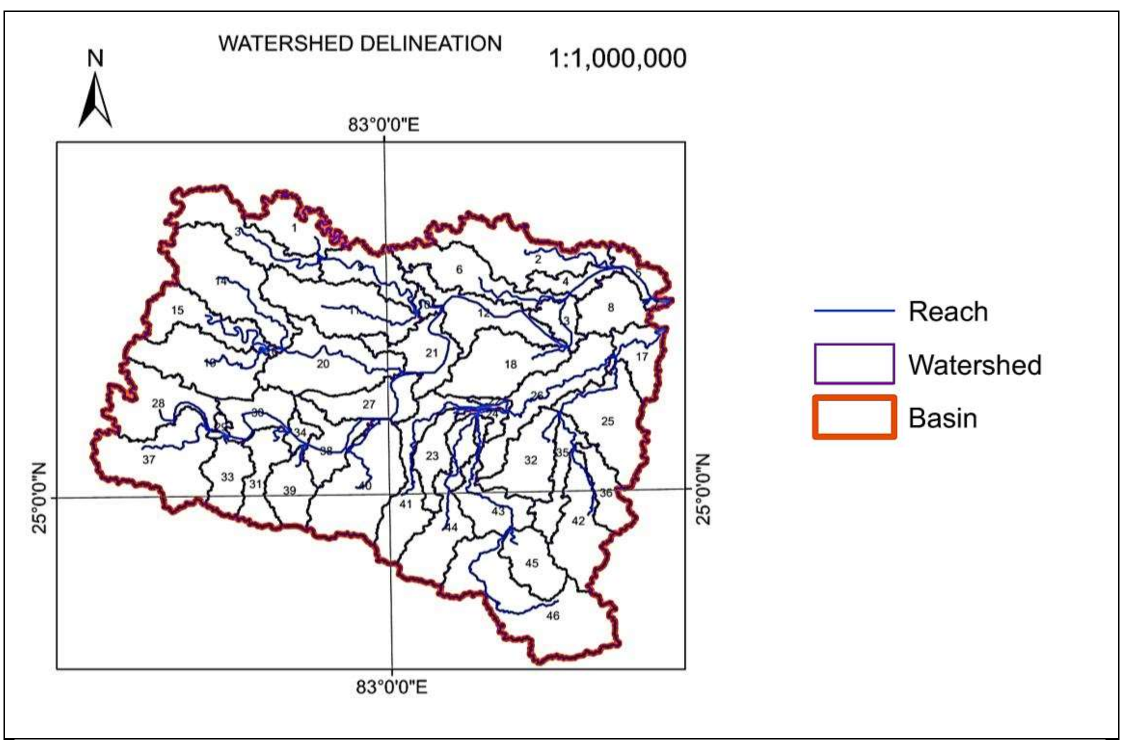


Figure 6.5: Watershed delineation

### 6.4.1 Soil and Water Assessment Tool (SWAT)

In this study, SWAT 2012 was utilized for hydrological modeling. ArcGIS 10 software was used along with its extension, ArcSWAT. The catchment was split into various sub-catchments, which were then further categorized into HRUs. Each HRU comprises a unique combination of soil characteristics, elevation, and LULC. The water budget was the primary impetus behind all forms, and the HRU was the unit used to estimate the hydrologic

parameters. These procedures were separated into two stages:

1) A land stage, wherein the SWAT mimics the catchment loadings of the stream, residue, and supplements from each HRU, which are then locale-weighted to the sub-basin level;
2) An in-stream stage, wherein the model tracks the course of the catchment loadings from each sub-basin throughout the channel organization.

A solitary plant-improvement model was utilized as a part of the SWAT in order to reenact extraordinary land-cover types including expansive information yield. This development model was utilized to evaluate the expulsion of water and supplements from the root zone, transpiration, and biomass generation. Planting, reaping, culturing passes, and supplement and pesticide applications could be recreated for each trimming framework with particular dates (Romagnoli et al., 2017). Once the data for each HRU were determined at the sub-basin level, the runoff, sediments, nutrients, and pesticides were routed through channels, ponds, reservoirs, and wetlands to the watershed outlet. The SWAT technical documentation version 2009 by Neitsch et al., 2009 can be used as a reference to learn more about SWAT modeling.

## 6.5 SWAT Results

In the present study, the SWAT model was run for a watershed located in the northern part of India in the state of Uttar Pradesh. The SWAT divided the watershed into 46 sub-watersheds and 760 HRUs for easy and accurate modeling. It was estimated that the average annual precipitation of the basin is 941.24 mm, snowfall is 0 mm, snowmelt is 0 m, surface runoff (Q) is 358.56 mm, lateral discharge is 1.39 mm, and groundwater discharge for shallow and deep aquifers is 138.69 and 8.53 mm, respectively. The average value for total aquifer recharge is 180.65 mm, the total water yield of the basin is 507.17 mm, and evapotranspiration is 411.7 mm. A pictorial representation of the SWAT output regarding runoff and evapotranspiration is shown in Figure 6.6. The results indicated that, on average, more than 45% of the total precipitated water is lost in runoff and evapotranspiration. The average monthly values of all the parameters of the basin—that is, rainfall, snowfall, surface runoff, lateral runoff, water yield, and evapotranspiration—are given in Table 6.2. It was also estimated that there is an average of 52.11 annual water-stress days and 10.54 temperature-stress days.

During watershed image classification, the watershed was classified into six classes according to the land use. It was found that most of the watershed is an urban or barren land. Table 6.3 gives the annual average values of the parameters according to each land use type. It was also concluded from the results that for urban land, surface runoff might be excessive, and less than 22% of the water yield is base flow. For range and agricultural land, surface runoff may be excessive. For barren land, the sediment yield may be overly high, more than half of the precipitation is lost to runoff, the surface runoff is the highest, and less than 22% of the water yield is base flow.

Table 6.2 Average monthly values of the parameters for the watershed.

| Month | Rainfall | Snowfall | SUR Q | Lateral Q | Water Yield | ET | SED | PET |
|---|---|---|---|---|---|---|---|---|
| Jan | 16.30 | 0 | 3.11 | 0.03 | 4.29 | 13.75 | 0.08 | 84.90 |
| Feb | 15.60 | 0 | 2.07 | 0.03 | 2.77 | 16.56 | 0.05 | 94.98 |
| Mar | 4.09 | 0 | 0.40 | 0.02 | 0.91 | 42.98 | 0.01 | 186.43 |
| Apr | 5.14 | 0 | 0.38 | 0.02 | 0.67 | 27.98 | 0.01 | 211.08 |
| May | 13.41 | 0 | 0.97 | 0.02 | 1.17 | 16.06 | 0.01 | 214.76 |
| Jun | 107.36 | 0 | 22.41 | 0.05 | 19.80 | 34.62 | 0.29 | 190.49 |
| Jul | 255.36 | 0 | 103.17 | 0.21 | 103.50 | 68.92 | 1.18 | 134.00 |
| Aug | 274.62 | 0 | 115.85 | 0.32 | 136.90 | 72.31 | 2.11 | 122.88 |
| Sep | 201.68 | 0 | 94.99 | 0.34 | 145.24 | 59.26 | 2.14 | 123.88 |
| Oct | 28.68 | 0 | 9.61 | 0.20 | 56.11 | 32.92 | 0.19 | 151.62 |
| Nov | 8.89 | 0 | 2.33 | 0.10 | 25.71 | 15.84 | 0.07 | 121.75 |
| Dec | 10.00 | 0 | 3.26 | 0.06 | 10.09 | 10.35 | 0.06 | 90.63 |

Note: SED is in $t \cdot hm^{-2,}$ and all other values are in mm. Q: discharge or runoff; ET: evapotranspiration; PET: potential evapotranspiration; SED: sediment yield.

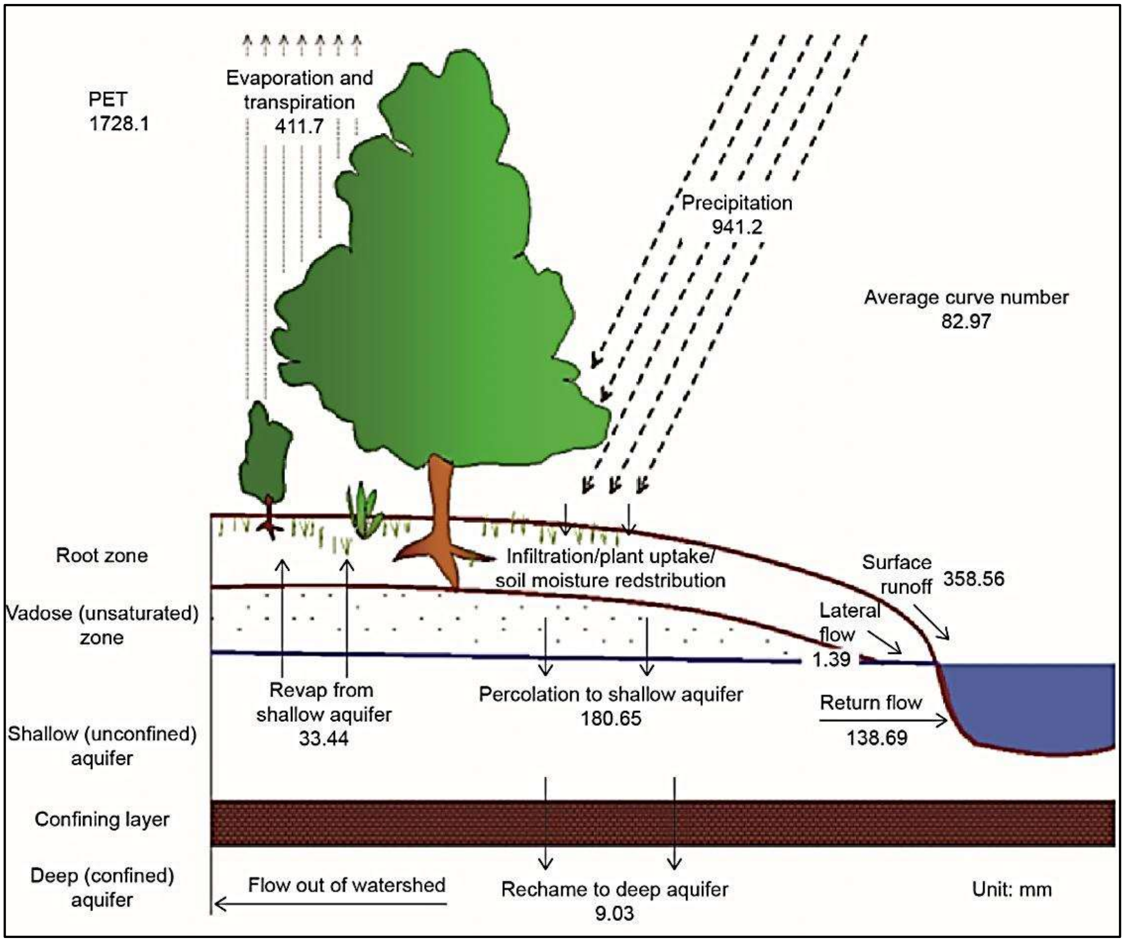


Figure 6.6 Pictorial representation of the SWAT output obtained from ArcSWAT 2012.

Sediment loss from the landscape is dependent upon many factors. Sediment overestimation in SWAT usually arises from inadequate biomass production; this often occurs with specific land uses. SWAT also modifies sediments to consider in-stream deposition and the erosion of stream banks and channels. Often, little or no measured data are available to differentiate between upland sediment and in-stream sediment changes.

Table 6.3 Average annual values of the parameters for each land type

| LULC type | Area ($km^2$) | CN | AWC (mm) | USLE_LS | Precipitation (mm) | SURQ(mm) | GWQ (mm) | ET (mm) | SED ($t·hm^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|
| WATR | 414.83 | 92 | 104.91 | 0.67 | 938.86 | 0 | 0 | 1374 | 0 |
| URBN | 5683.33 | 83.21 | 102.13 | 0.18 | 917.93 | 422.43 | 84.19 | 370.26 | 3.45 |
| RNGE | 5233.7 | 80 | 103.27 | 0.26 | 936.31 | 294.35 | 200.57 | 393.7 | 4.71 |
| AGRL | 1071.0 | 84. | 105.53 | 0.48 | 959.55 | 360.58 | 164.57 | 388.9 | 11.92 |
| BARR | 1268.0 | 92 | 106.89 | 0.31 | 947.23 | 556.68 | 33.29 | 327.5 | 29.27 |
| FRSD | 1948.2 | 80. | 118.56 | 0.98 | 1008.96 | 291.12 | 226.44 | 442.5 | 1.38 |

Note:- AWC: available water content capacity; CN: curve number; GW Q: groundwater discharge; USLE_LS: universal soil loss equation slope length factor.

Streams may be either net sources or sinks for sediment. In-stream sediment modification is impacted by the physical channel characteristics (i.e., slope, width, depth, channel cover, and substrate characteristics) and the quantity of sediment and flow from upstream. As a result, it was estimated that the maximum sediment yield is higher than 50 t·hm−2 in at least one HRU. The highest value is from HRU #473, sub-basin #36, which is barren land with Vc7-3a-2 soil. It was also estimated that the total sediment load of the basin is 6.198 t·hm−2.

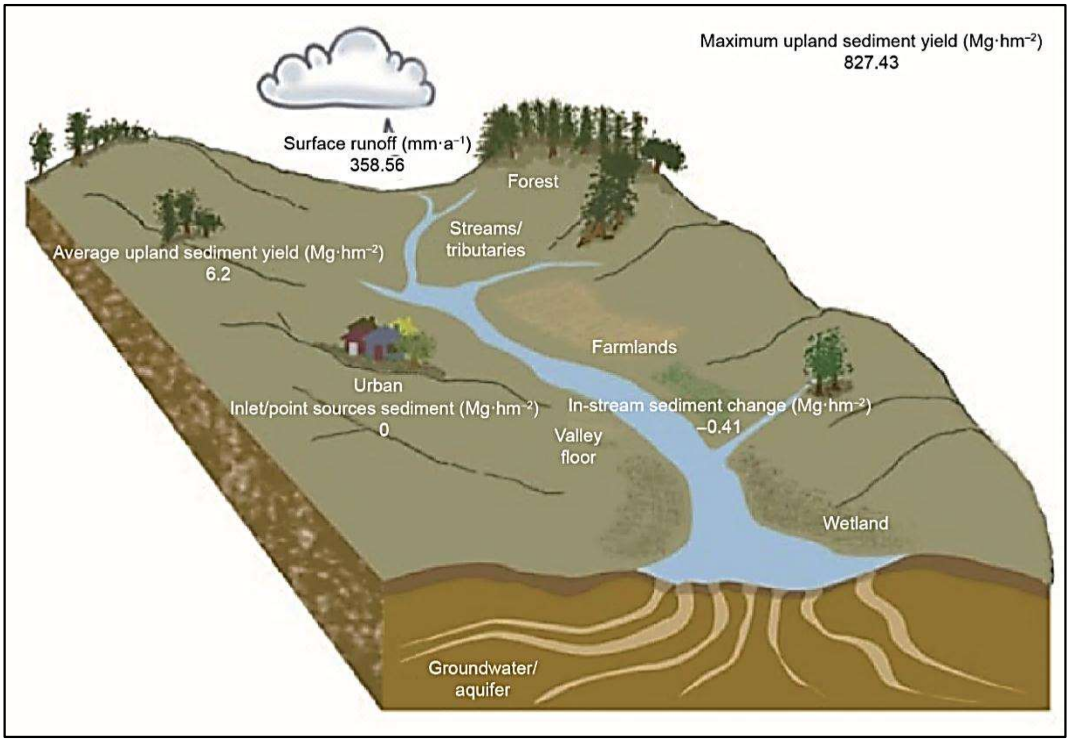


Figure 6.7 SWAT output for sediment yield obtained from ArcSWAT 2012.

A pictorial representation of the SWAT output obtained from ArcSWAT 2012 regarding sediment yield is shown in Figure 6.7. It was concluded from the results that the average upland sediment yield is 6.2 Mg·hm−2 and the maximum upland sediment yield is 827.43 Mg·hm−2.

## 6.6 Conclusion

The soil is the natural, dynamic, heterogeneous, non-renewable resource, which supports plant and animal life. Soil and water problems in U.P. 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 soil resources. In this chapter Soil and Water Assessment Tool (SWAT) is used to model sediment yield processes of Varanasi watershed in the Ganga basin. Twenty years of daily meteorological data, soil data procured, Digital Elevation Model and satellite imagery are used as inputs. The watershed was divided into 46 sub-basin for analysis and modeling. 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 would be 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 improving water and soil quality of the watershed.

# CHAPTER 7. A COMPARISON OF SWAT MODEL CALIBRATION TECHNIQUES FOR HYDROLOGICAL MODELING IN THE GANGA RIVER WATERSHED

## 7.1 Introduction

In terms of the land and climate characteristics of the southern part of Uttar Pradesh Basin, tendencies toward sudden floods and soil erosion present some of the most extreme issues. Because of soil erosion, the soil of this watershed is continuously degrading and losing nutrients, thus affecting agriculture in the state. The severity of the issue is intensified in arid and semi-arid lands, where short-duration intense rainfall and unsustainable land use have quickened soil losses by erosion. Detailed and accurate information regarding soil erosion and surface water discharge is helpful for watershed managers to manage better and conserve natural resources such as soil and water, and to promote sustainable development. At present, various procedures are used for hydrological modeling, utilizing precipitation, land use, and soil characteristics information. Among these strategies, the SWAT is a process-based hydrological model developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) (Kumar et al., 2015). New algorithms have been developed to best estimate the parameters used in hydrological modeling.

The SWAT is widely used for hydrological and sediment yield modeling. It is a time-consistent and spatially appropriate test model that was developed to assist watershed managers in anticipating the effects of land use management activities on runoff, soil erosion, and agricultural chemical yields (Khalid et al., 2016). Specialists have effectively used the SWAT for runoff assessments (Salimi et al., 2016, Noori et al., 2016), water