

CHAPTER-4

HYDROLOGICAL MODELING WITH THE SOIL AND WATER ASSESSMENT TOOL (SWAT)

4.1 Introduction

To study the groundwater level, understanding of the impact of different factors like meteorological characteristics, hydrological parameters etc. is very important. In this chapter SWAT analysis is done to find out the different hydrological parameters like evapotranspiration, water yield, ground water recharge, runoff etc. of the study area. The primary goals of this chapter are to assess the execution of the SWAT in the Varanasi watershed and to demonstrate and survey the practicality of utilizing SWAT for hydrologic modeling in this region. In the following sections methodology adopted for SWAT analysis, Data used, it's processing and results obtained along with discussion have been presented.

4.2 Methodology

For SWAT analysis, detail of the study area considered is presented in Chapter 3. The whole study area was divided into 27 sub-watersheds. The details of watershed are presented in table 4.1 and figure 4.1. Selection of Watershed was done by ARC-GIS tool.

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Table 4.1:- Details of sub watershed Area

Sub watershed	Area(ha)	Sub watershed	Area(ha)
1	889.49	15	525.66
2	901.00	16	83.55
3	17.83	17	642.34
4	329.82	18	1702.29
5	1311.72	19	607.81
6	954.95	20	1478.42
7	1094.21	21	557.74
8	1550.55	22	1809.03
9	1236.01	23	306.10
10	22.66	24	462.50
11	1005.82	25	2790.90
12	886.94	26	5241.02
13	1109.76	27	1808.07
14	67.300		

The flow diagram explaining the details of SWAT analysis considered is presented in Fig. 4.2. 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 of Varanasi station for the period of 1996 to 2020 were used. 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 Hydrological Response Units 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 Hydrological

Response Units and sub-watershed.

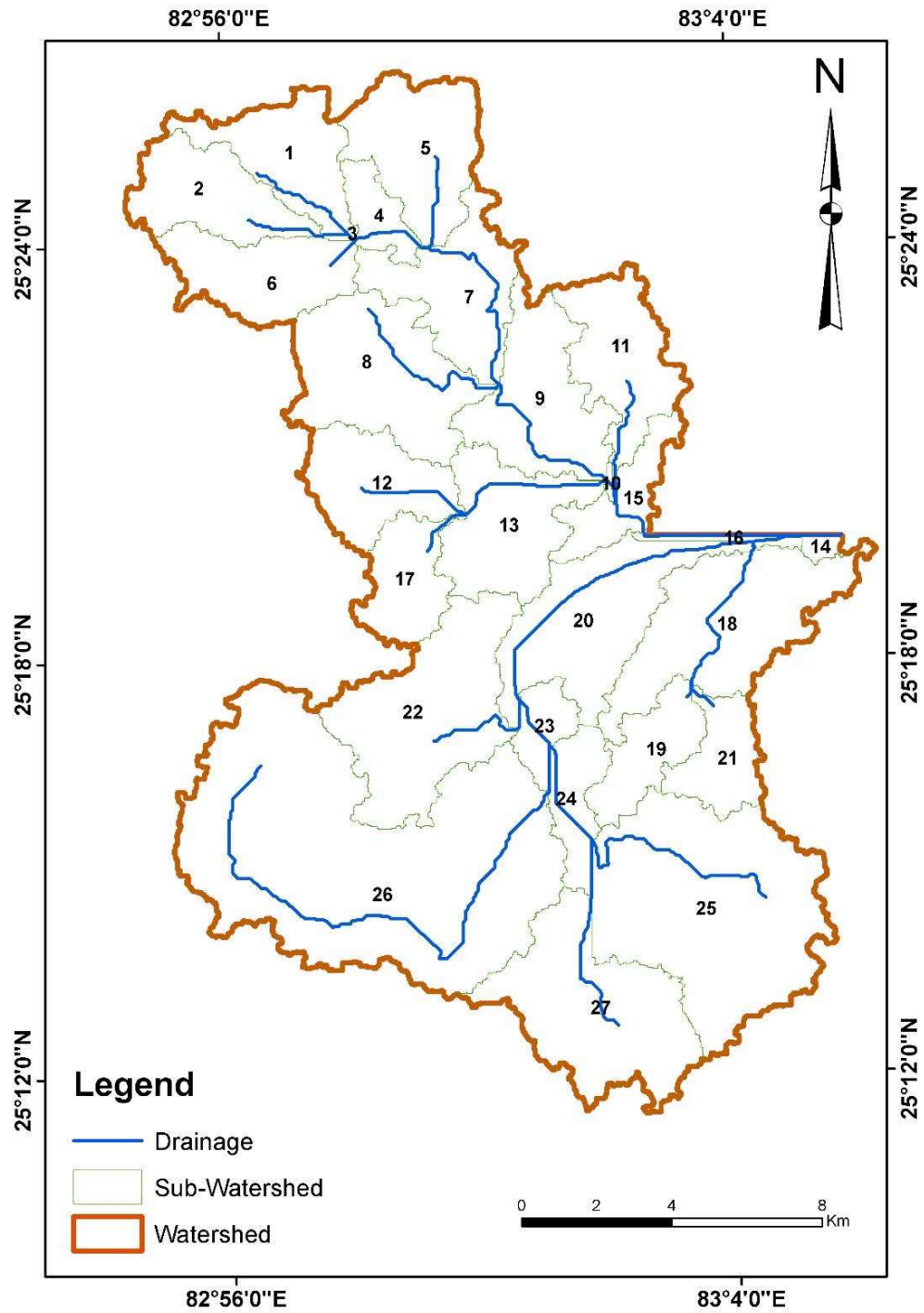


Figure 4.1: - Sub-watershed considered in the study

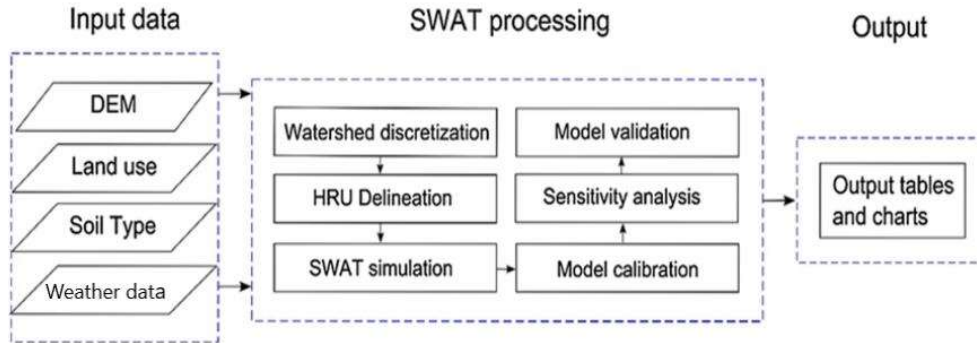


Figure 4.2 Methodology used for SWAT Analysis

4.3 Data Collection and Technology Used

Details of the different data and technology used are presented in the following sections.

4.3.1 Data used

As input data DEM image, Soil map indicating soil type and properties, Land Use Land Cover (LULC) data and metrological data were used in this investigation. The DEM data was obtained from United State Geological Survey (USGS). Fig. 4.3 shows the DEM data of study area.

The soil map used is presented in Fig. 4.4. The soil data was procured from NBSS (National Bureau of Soil Survey) and the data was validated by lab testing. For this, the land was divided into two soil layer with a depth of 30 cms each. It can be observed that the three different types of soil clayey loam, silty loam and Sandy loam were present in the considered region. The detail properties of these soil type are presented in the Table 4.1. It can be noted from the figure 4.4 ,that the clayey loam is covering the most of the area. The sandy loam is concentrated in the small region of the study area. Slope map of the study area is presented in figure 4.5 ,whereas figure 4.6 shows the Land use and Land cover map. Image categorization for the LULC map was done using Landsat 8 satellite images. For spatial data, Earth Explorer USGS obtained

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Landsat-8 Thematic Mapper (TM) multispectral pictures from November 2015 and 2016 with row and path (141,42), (141,43), and (141,42) for LULC mapping. For watershed delineation, the USGS earth explorer website provided a 30 m resolution Shuttle Radar Thematic Mapper (SRTM) Digital elevation model (DEM) covering a region from longitude 82°56'0" E to 83°4'0" E and latitude 25°12'0" N to 25°24'0" N. LULC map indicates that whole region is covered by five types of land cover which are water, forest, agricultural land, urban land and barren land. The most of the area is occupied by agricultural cover.

Indian Meteorological Department Pune, provided daily meteorological data from 1996 to 2020. A two fold mass curve approach was used to assess the data's consistency. Data for daily rainfall, temperature, sun radiation, and pressure were used for meteorological input throughout 24 years.

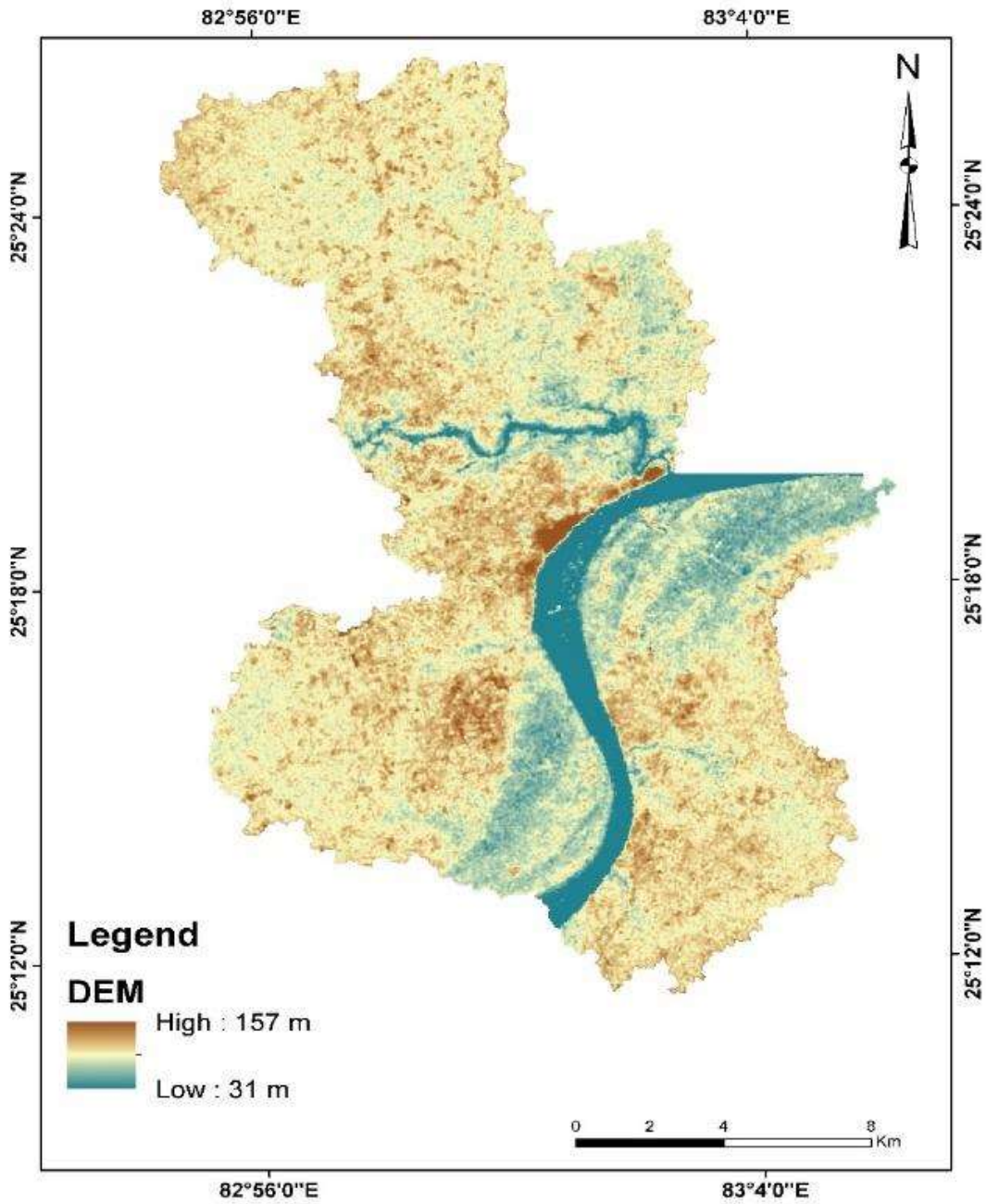


Figure 4.3 DEM data of the study area

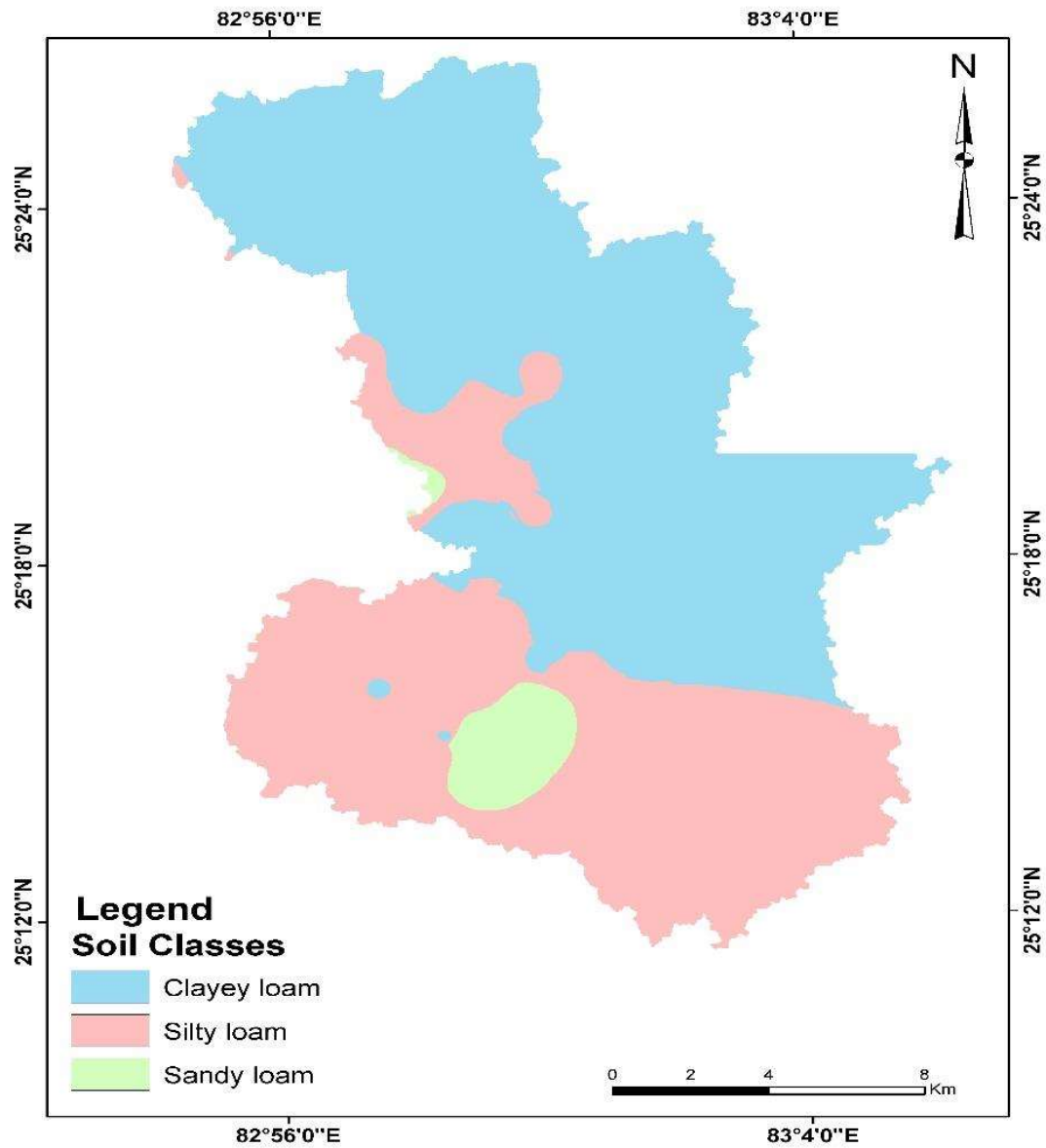


Figure 4.4 Soil Map of study area

Table 4.2: - Details of Soil Classes

Soil Classes	Hydraulic Conductivity
Clayey loam	7.60- 16.79mm/hr
Silty loam	16.80 - 21.28 mm/hr
Sandy loam	21.28 - 35.50 mm/hr

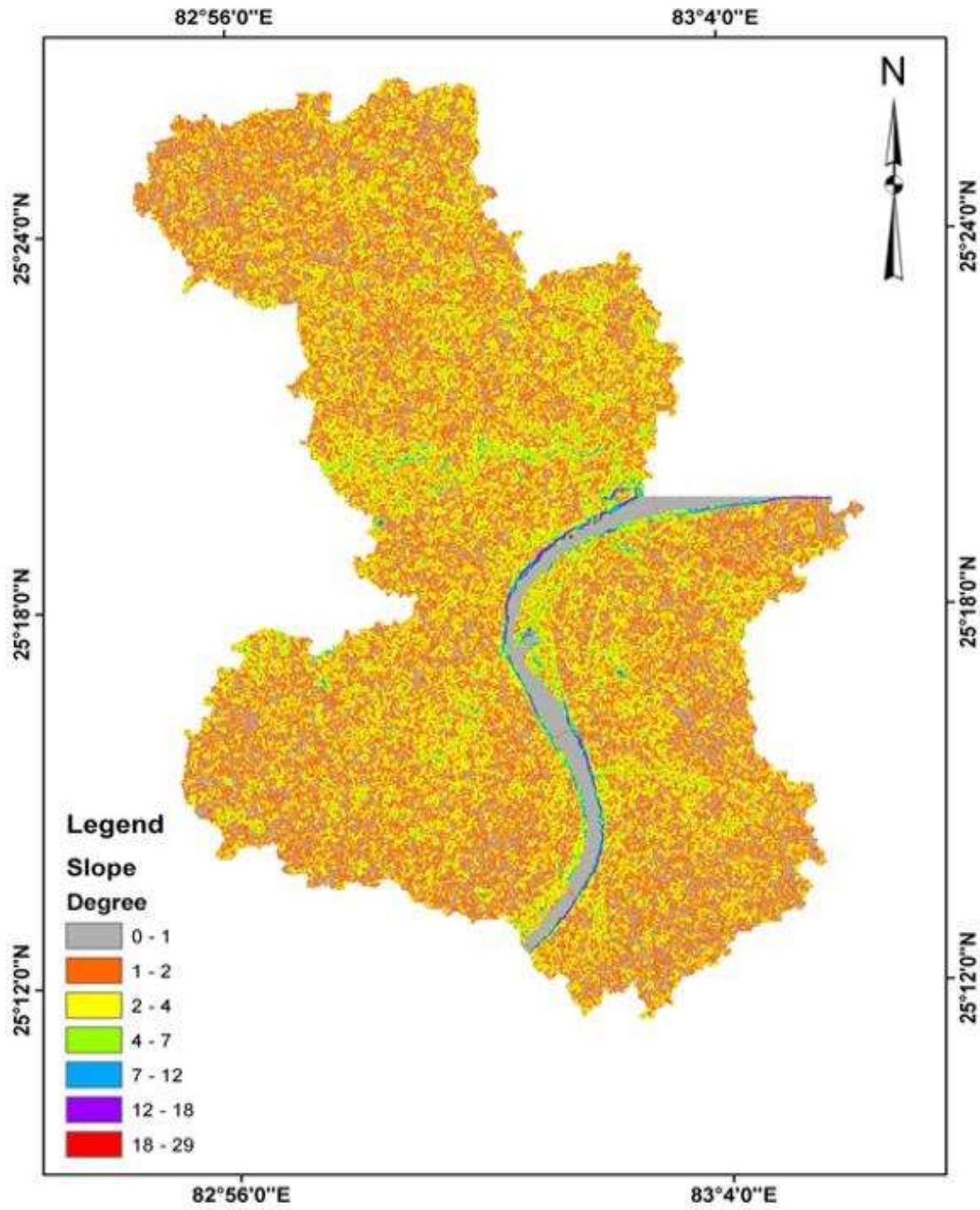


Figure 4.5 Slope map of the study area

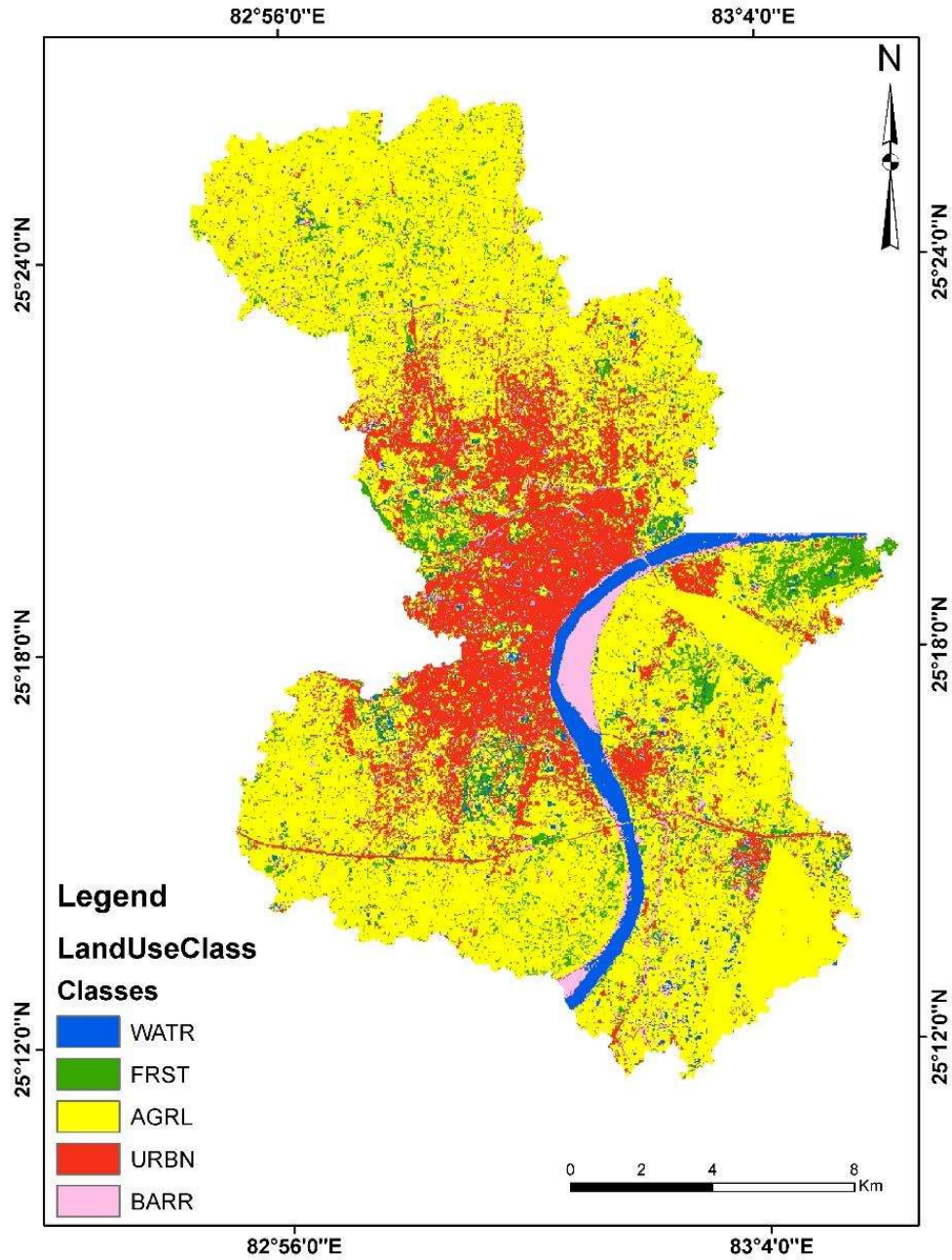


Figure 4.6 LULC map of the study area

Table 4.3: Land use classification of the study area.

Land use Classification	Area
Water Body	13.7 Km ²
Vegetation	21.28 Km ²
Built-up Area	58.06 Km ²
Agricultural Land	188.98 Km ²
Sand Bars And Barren Land	11.78 Km ²

4.3.1 Remote sensing

Remote sensing uses radiation reflected or emitted from objects at or near the Earth's surface and atmosphere to offer information about those items. The information is frequently taken in the form of image data from a distance. By examining photos collected at different moments in time, we can determine the composition and nature of the Earth's surface and atmosphere at local, regional, and global sizes, as well as assess changes. Remote sensing is useful in this regard since it can provide spatial information that would otherwise be difficult or impossible to get. Remote sensing is important for visualising (offering alternate and synoptic viewpoints) and characterising human settings in the social sciences. Researchers in the social sciences frequently combine remotely sensed data or its derivatives with other data sources, Congalton, R. G. (2010).

4.3.2 Geographical Information System (GIS)

A geographic information system (GIS) is a software platform that allows you to capture, store, query, analyse, and display geospatial data, Chang, K. T. (2016). Both the location and properties of spatial features are described by geospatial data. GIS is made up of hardware, software, data, people, and organisations. GIS grew in popularity in the 1980s, thanks to the development of personal computers (PCs) and graphical user interfaces. GIS is now widely used in a variety of disciplines, including resource management, emergency planning, criminal analysis, public health, land records management, precision farming, and many more. GIS isn't just a piece of software. People and methods are integrated with geospatial software and technologies to enable geographical analysis and data management.

4.4 Data Processing

4.4.1 Image Classification

An image is a matrix of pixels in which each cell has a different Digital Number (DN), which represents the intensity value of each pixel. The process of automatically identifying each pixel in a raster environment based on their different spectral reflectance is known as image classification. This classification technique can be handled in two ways: supervised and unsupervised. The unsupervised image classification consequently bunches cells into groups automatically dependent on the measurements of their digital numbers (DNs), (Lillesand et al., 2004). This procedure involves negligible user effort; the user only has to choose the number of classes he wants to classify the image in, the unsupervised classification technique is entirely automatic. In supervised classification, the operator manually controls the inputs, agreeing with the operator's knowledge to impact the results. In this process, the operator creates the signature classes on its own and gives them as input to the software.

4.4.2 Methodology for Land Use/ Land Cover

The complete procedures for prioritization using LULC analysis are shown in Figure 4.7. Changes in Land Use/Land Cover (LULC) are an important and controversial topic in the current situation, as the world's population grows quickly. So analysis and mapping of LULC became an essential part of any study. It is a critical component that can help in developing various indexes for the conservation of natural resources when it integrates with other studies. Vegetation, an essential aspect of LULC, is defined as the environmental condition of the earth's surface and sub-surface.

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This term refers to vegetation type land cover that includes agricultural land and other physical aspects, such as biodiversity, soil surface, and human settlement.

It is critical to check DEMs for null values before using them in a project. If null values are present, image processing must remove the null values. The Fill function of ArcGIS 10 was used to eliminate null values from DEMs in this project. All of the DEMs were Mosaicked using the image processing application Erdas, imagine after they were corrected. Figure 4.3 depicts the mosaicked DEM. The Land Use/ Land Cover (LULC) map was created using satellite photos. Landsat 8 pictures were first stacked using image processing, then mosaicked, and finally supervised image classification was performed using an image interpretation tool. BARR (Barren Land), URBN (Urban Area), FRST (Forest Land), AGRL (Agricultural Land) and WATR (Water Body), were used to classify the image as shown in table 4.3.

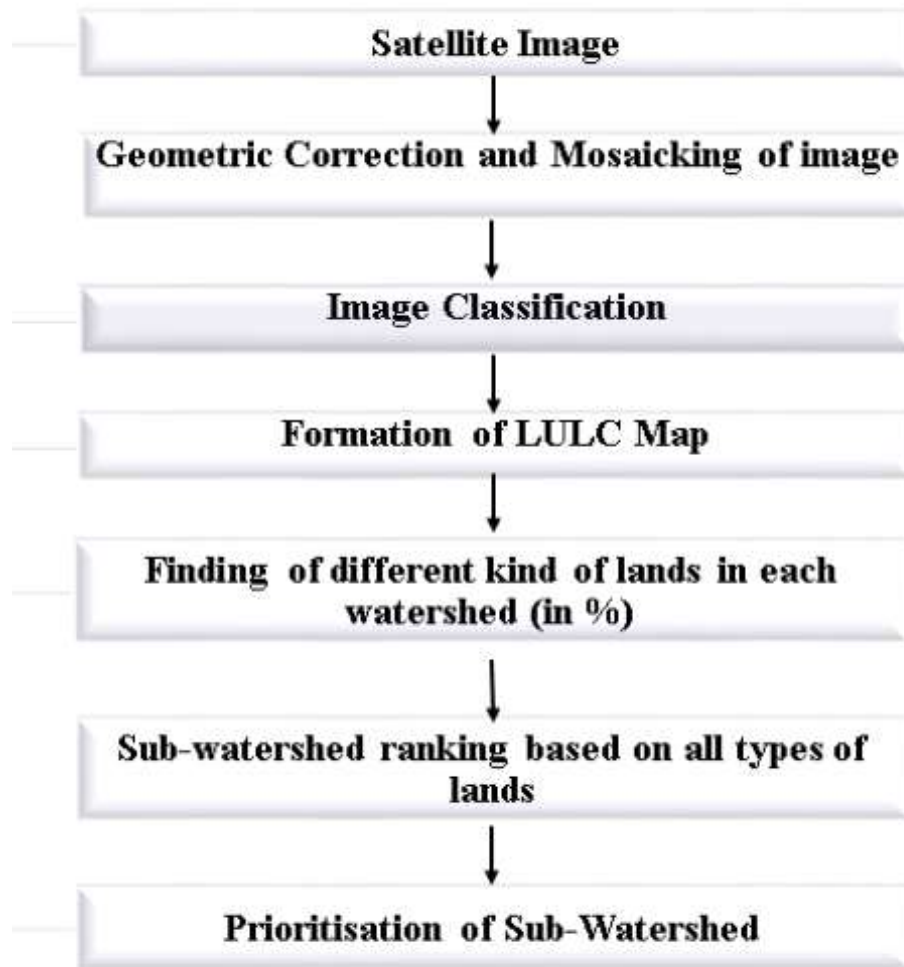


Figure 4.7- Flow chart of Prioritization using LULC analysis

4.4.3 SWAT Analysis

The flowchart of the approach utilized in this investigation is shown in Figure 4.7. SWAT 2012 was the primary tool utilized in this study to demonstrate the watershed's hydrology. SWAT is a model at the watershed level. It's a time-based, process-based concept that works in daily steps and employs a command structure to direct overflow and chemical compounds through the watershed. Within a single morphometric divide, the watershed includes both the catchment and the drainage channel. It's a naturally occurring hydrologic unit defined by natural borders and shared

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characteristics such as physical attributes, land surface topography, and climatic circumstances. Watershed delineation is the process of drawing lines on a map to define the boundaries of a watershed. These are frequently depicted on maps using DEM or contour map data.

SWAT modeling begins with the definition of watersheds. In this stage, DEM is used as the input. Along with the slope of the watershed, the streams and outlet points are generated. The watershed is defined based on the outflow points chosen by the researcher. 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 27 sub-watersheds. Figure 4.1 shows the delineated watershed, streams, and monitoring points of the study area and the next step of the analysis 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 27 HRUs. In the next step, the climate database is provided. Finally, the SWAT model was run for 20 years to determine the runoff, evapotranspiration, and sediment yields for each sub-watershed and HRU.

The hydrologic cycle as simulated by SWAT is based on the water balance Equation

$$SW_t = SW_0 = \sum_{i=1}^j (R_{\text{day}} - Q_{\text{surf}} - Ea - w_{\text{seep}} - Q_{\text{gw}}) \quad 4.1$$

Where,

- SW_t is the final soil water content (mm H₂O),
- SW_0 is the initial soil water content on day i (mm H₂O),

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- t is the time (days),
- R_{day} is the amount of precipitation on day i ($\text{mm H}_2\text{O}$),
- Q_{surf} is the amount of surface runoff on day i ($\text{mm H}_2\text{O}$),
- E_a is the amount of evapotranspiration on day i ($\text{mm H}_2\text{O}$),
- W_{scep} is the amount of water entering the vadose zone from the soil profile on day i ($\text{mm H}_2\text{O}$), and
- Q_{gw} is the amount of return flow on day i ($\text{mm H}_2\text{O}$).

The water budget equation 4.1 is based upon the conservation of mass of water. Runoff, evapotranspiration, groundwater storage etc. are different forms on earth. SWAT was used for hydrological modeling in this investigation. The software ArcGIS 10 and its extension, ArcSWAT, were used. The catchment was divided into different sub-catchments, which were then classified into HRUs. Each HRU is made up of a different set of soil properties, elevation, and LULC. The HRU was the unit utilized to estimate the hydrologic parameters, and the water budget was the driving motive for all forms.

4.4.4 SUFI-2 Analysis

For sensitivity analysis SUFI-2 model was used. This helps to improve the watershed model by uncertainties analysis, Khalid, K. et al. (2016). SUFI-2 was used for calibration and validation of the SWAT model in the present study. To assess the quality of calibration and sensitivity analysis three measures are used. The first is the 95 percent prediction uncertainty (95PPU). The second and third measurements are 'Nash-Sutcliffe Efficiency (NSE) and 'Coefficient of Determination (R^2). The 'Nash-Sutcliffe Efficiency' (NSE) can be written as

$$NSE = 1 - \frac{\sum(O-C)^2}{\sum(O-\bar{O})^2} \quad 4.2$$

$$R^2 = \frac{\sum(\hat{O}-C)^2}{\sum(O-\bar{O})^2} \quad 4.3$$

Here, O = Observed data, \hat{O} = Predicted data, \bar{O} = Mean of observed data and C = Computed data

4.5 Results and Discussion

4.5.1 Calibration and Validation

Calibration was done by the help of monthly flow data. Three-year data from 2015 to 2017 were used for the calibration purpose, while two-year data from 2018 to 2020 were used for validation. Calibration was done in SWAT-CUP by using SUFI-2. In SWAT-CUP, different options for the calibration are available. Here SUFI-2 was used in this study for calibration and validation. The comparisons of actual and predicted data after calibration and validation stage are presented in Fig. 4.8 and Fig. 4.9. Both of the figures have shown that the discharge can be predicted by the model satisfactorily. Table 4.4 shows the calibration and validation statistics of the analysis obtained from SUFI 2. It can be observed that R^2 value for calibration and validation are 0.98 and 0.96, respectively. NSE for calibration and validation are 0.92 and 0.91, respectively.

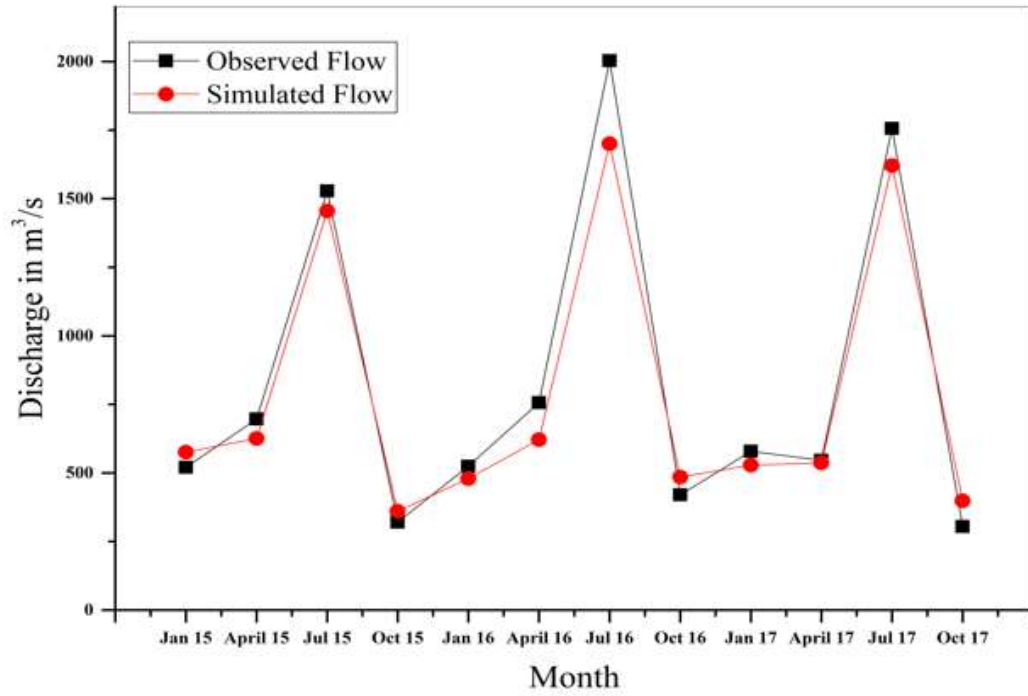


Figure 4.8 Comparison of observed and actual data after calibration

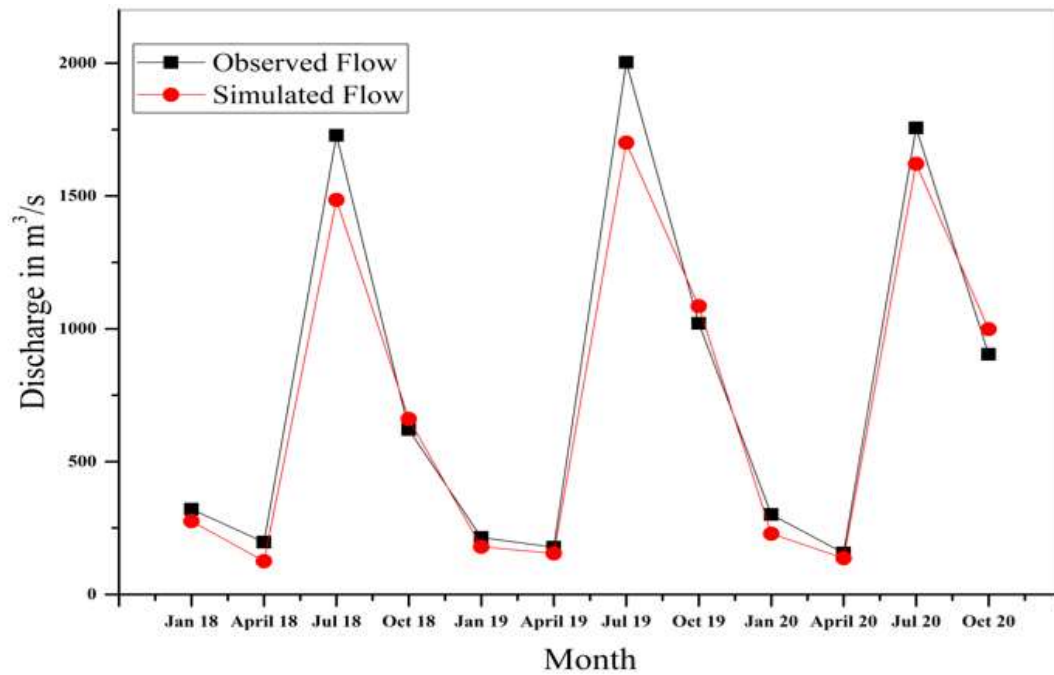


Figure 4.9 Comparison of observed and actual data after validation

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Table: 4.4 calibration and validation statistics

Variable- outlet discharge	R²	NSE	bR²	MSE	SSQR	PBIA S	KG E
Calibration	0.98	0.92	0.9492	9.00E+03	8.90E+03	4.4	0.93
Validation	0.96	0.91	0.9354	8.90E+03	9.30E+03	4.3	0.92

4.5.2 SWAT Results

The SWAT model was used in this work to simulate a watershed in Varanasi, India's northernmost state. For quick and accurate modeling, the swat divided the watershed into 27 sub-watersheds and 27 HRUs. The average annual precipitation in the basin is 969.7 mm, with 0 mm of snowfall, 0 m of snowmelt, 340.58 mm of surface runoff (q), 1.32 mm of lateral flow, and 150.25 and 22.36 mm of groundwater discharge for shallow and deep aquifers, respectively. Total aquifer recharge averages 177.61 mm, total water yield averages 507.17 mm, and evapotranspiration averages 395.6 mm.. According to the findings, more over 45 percent of total precipitated water is lost through runoff and evapotranspiration on average. The Table 4.5 shows average monthly values of the parameters for the watershed.

Fig. 4.10 shows the Variation of Precipitation, Evapotranspiration, Ground Water Recharge, and Water Yield for different years. It can be observed that the magnitude of the precipitation, Evapotranspiration etc. are maximum from mid-June to mid-August.

The annual variation of the precipitation, evapotranspiration, ground water recharge and water yield is presented in Fig. 4.11. It can be observed that the most of the loss of water takes place through evapotranspiration and surface water yield. The amount of water stored in ground water through recharge is comparatively less. This

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indicates that the through more and more artificial recharge such loss can be suppressed.

Table: 4.5 Average Monthly water budget of study area from 2015 to 2020

Month	Rainfall	Snowfall	Surf Q	Lat (mm)	Water yield	ET(m m)	SED Yield(mm)	PET(m m)
January	6.95	0	0.09	0.04	3.3	5.14	0.01	67.98
February	3.15	0	0.01	0.02	1.27	7.61	0	102.98
March	4.3	0	0.14	0.01	1.05	12.63	0	183.35
April	16.69	0	0.45	0.01	1.1	55.1	0	219.8
May	32.5	0	0.22	0.01	0.77	70.6	0	276.6
June	126.	0	3.06	0.02	3.32	56.3	0.03	215.36
July	295.6	0	58.63	0.18	70.46	60.39	2.46	148.51
August	265.3	0	34.38	0.3	80.73	47.3	1.89	135.92
September	187.	0	29.6	0.29	77.18	56.2	2.25	155.36
Oct	22.12	0	6.86	0.23	47.28	20.1	0.76	123.7
Nov	0.6	0	0	0.12	12.32	2.14	0	99.63
Dec	7.58	0	0.81	0.07	7.35	1.95	0.07	70.36
Total	969.0	0	134.25	1.3	306.13	395.46	7.47	1799.55

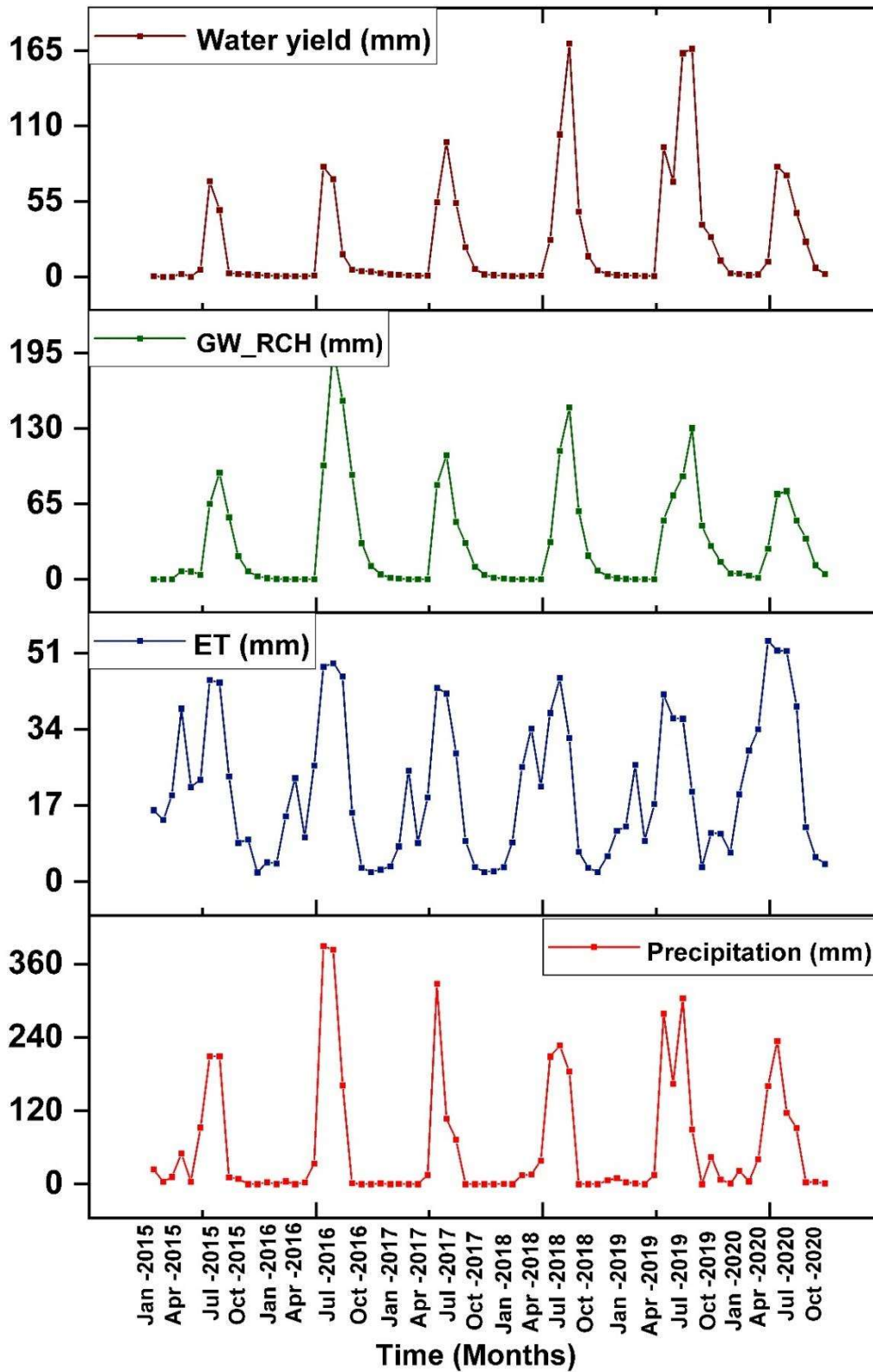


Figure: 4.10 Variation of Precipitation, Evapotranspiration (ET), Ground Water Recharge (GW_RCH), Water Yield (WYLD_QMM) for different years

Note: All other parameters are in mm, except SED in $t \cdot hm^{-2}$.

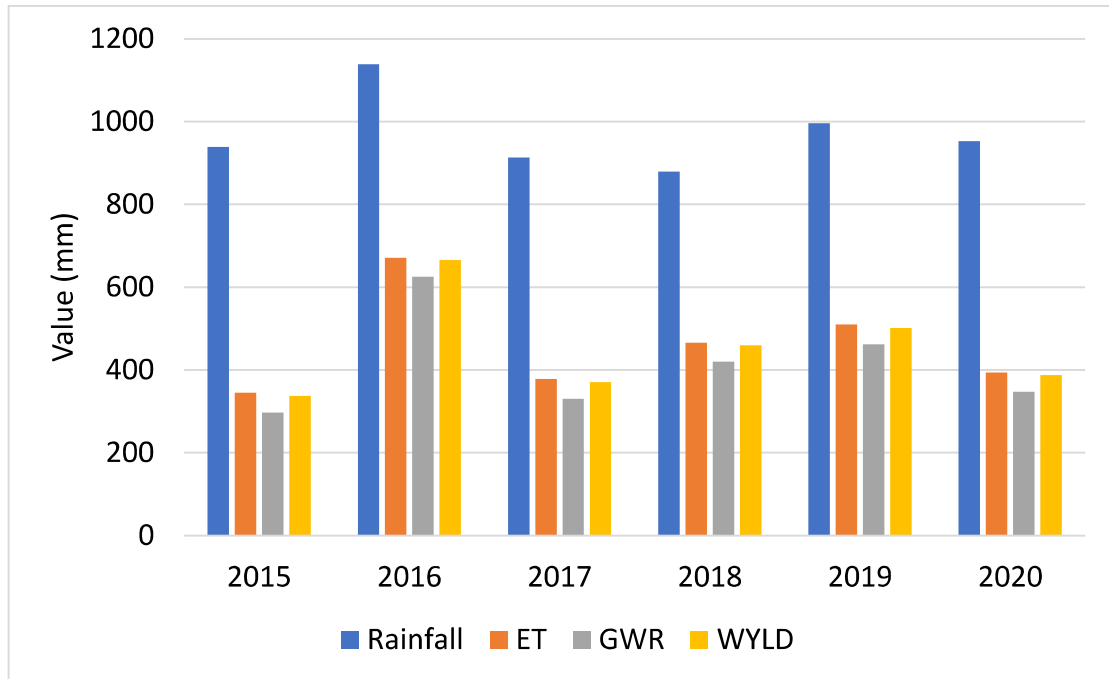


Fig. 4.11 Annual Variation of the Rainfall, Evapotranspiration (ET), Groundwater recharge (GWR), Total surface water Yeild (WYLD) from 2015 to 2020.

Table 4.6 shows the average annual budget obtained SWAT analysis. From these data it can be observed that most of the water loss annually is taking place due to the Evaporation and transpiration process. The loss of the water due to return of water to river is around 151.86 mm. The ground water recharge of shallow aquifer is around 10 times much higher than the recharge of deep aquifer. Fig. 4.12 shows the pictorial view of the SWAT output obtained from ArcSWAT. It shows all the modes of movement of water along with the magnitude of the variation.

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Table: 4.6 Annual average water budget of study area

Sr No	Parameter	Values (mm)
1	Precipitation	969.7
2	Evaporation and Transpiration	395.6
3	Recharge to the deep aquifer	15.65
4	Percolation to shallow aquifer	150.25
5	Revap from Shallow aquifer	22.36
6	Average curve number	81.6
7	Return flow to river	151.86
8	Surface Runoff	340.58

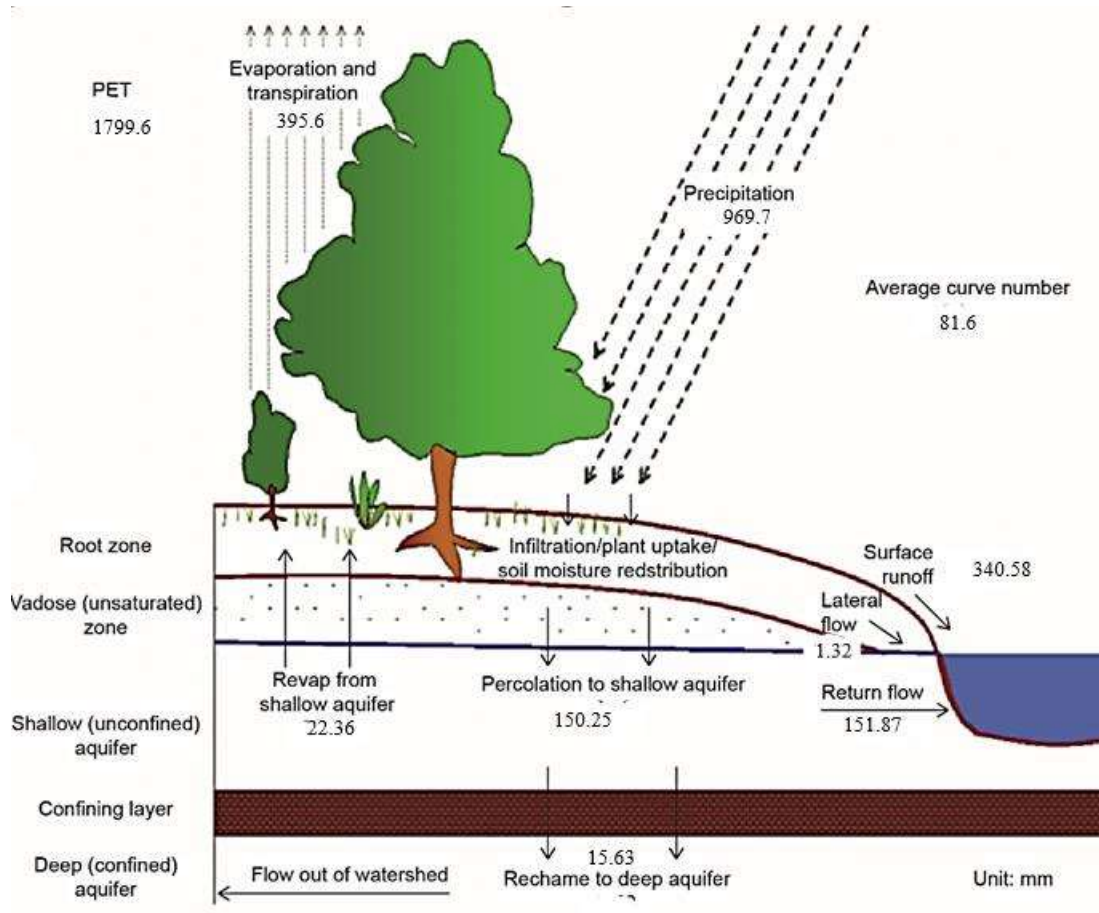


Figure 4.12 Pictorial representation of the SWAT output obtained from Arc SWAT

4.6 Conclusion

- In the present chapter, SWAT analysis was done to find out hydrological settings of the study area. ArcSWAT was used for the analysis. DEM, LULC data, Soil data, slope data etc., were used as input for the analysis. The analysis was done on the 27 sub-basin. SUFI-2 algorithm (Sequential Uncertainty Fitting version 2) has been used for the calibration and validation along with through the SWAT-CUP interface that also accounts all the sort of uncertainties. Single point calibration and validation has been performed with discharge data at the outlet of the basin. The SWAT model was run for the calibration period of 2015-2017 and validation period of 2018-2020. Various model evaluation statistics, i.e., Nash-Sutcliffe efficiency (NSE), Percentage Bias (PBIAS), Coefficient of Determination (R^2), and Root Mean Square error observation standard deviation ratio (RSR) was used to check the model performance. Based on the recommendation provided by Moriasi et al., 2007; (NSE > 0.75; PBIAS < $\pm 10\%$ and RSR < 0.5), the overall SWAT model performance for the concern study area is found to be very good during calibration and validation period in respect of discharge. More than half of the annual precipitation water is lost through evapotranspiration and runoff, according to the findings. About 40.1 percent of evapotranspiration takes place in the entire study area, whereas return flow to the river Ganga is 15.63%. Total surface runoff is 35.12%, and only 8 % of rainwater is going to deep aquifer. Evapotranspiration and Recharge have been used as input for groundwater flow modeling (MODFLOW) in the next chapter.