RAINFALL RUNOFF MODELLING OF BHATSA BASIN BY USING GIS

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Abstract : The entire life system is depending upon two major resources land use and water, so management is required for these resources for optimum utilization. It can be achieved by understanding their characteristics. Hence Rainfall Runoff Modelling plays important role for water management. This Hydrological modelling can be done for this purpose by using various techniques. In the present study, hydrological model named Soil Water assessment tool (SWAT) is used for the determination of hydrological properties of the Bhatsa river basin in Maharashtra, India. The annual average rainfall of the basin is raging from 2000 to 4000 mm. The rainfall intensity is max from June to September and it's zero in the remaining eight months. To manage the water deficiency problem, Kothale and Nadgaon rain gauge stations are selected. This study uses total 3 years of data from year 2013 to 2015.This study requires input data such as Meteorological data (Soil condition, Climatic condition etc) and GIS data (Digital Elevation Model, Land use/land cover data, soil data etc). Meteorological data was taken from the Bhatsa dam office, Shahapur. DEM data was taken from the SRTM (Shuttle Radar Topography Mission), Land use/land cover data was searched from Landat8 OLI software. SWAT simulation is done by following watershed basin delineation and Hydrological Response Unit (HRU) analysis. It is observed that after simulation observed stream flow is found to be max in year of 2015 i.e. 10 cm^3.It happens because of shortage of data. Calibration is needed for the model. hence, After calibration of model was done from period of 2013 to 2015 by using observed data. Calibrated model is further validated for year 2014 for getting better results. Efficiency of model can be done by using R^2 and Nash Sutcliffe Efficiency (NSE). Model got results of NSE as 0.71 and 0.735 for calibrated and validated period respectively. It is having R^2 value as 0.8130 which is considered as satisfactory result.

IndexTerms **- Rainfall runoff modelling, Arc SWAT, DEM, HRU.**

I. INTRODUCTION

For the survival of human beings Food, Water, and Shelter is very important parts. Water is the main source which is used for irrigation, hydroelectricity generation, and agricultural, industrial and domestic purpose. Availability of this water source is decreasing day by day because of its high demand. Rapid urbanization and increased population are the main reasons for the deficiency of the source. Occurrence of the source can be completed through the hydrologic cycle process. If this process of cycle does not work properly or affected by some parameters, these resources affect the development of the nation. So the quality use of available water resources and its proper supply becomes major issue at every level. For reducing the water management problem, Water resource engineer as well as hydrologist should do the analysis of hydrological processes, because all these hydrologic processes are connected with the climate, geology and use of watershed land. For minimizing this problem, modelling can be adopted. "Hydrological modelling helps both practicing water resources engineers and the research hydrologists who are studying the planning and development of integrated technique for management of water resources". (Schultz, 1993). The hydrological modelling is also useful for forecasting the accurate stream flow which is important component of watershed planning and sustainable water resource management". (Swain, 2013).

II. SWAT MODEL

SWAT (Soil Water Assessment Tool) had developed by the United States Department for Agriculture, Agricultural Research Service (USDA-ARS) (SWAT manual, 2012). As per Neitsch et al., 2001,"SWAT is a river basin scale model which is developed to quantify the impact of land management practices in large, complex catchments" SWAT (Soil Water Assessment Tool) helps to identify the Surface runoff, percolation, Evapotranspiration, erosion, nutrient and pesticide loading, crop growth and irrigation, groundwater flow, channel transmission losses, pond and reservoir storage and channel routing" (Neitsch et al. 2001). According to the Neitsch et al.2001, "SWAT model partitions or divides a watershed into no of sub watersheds. Then it organizes input information like Climate, Hydrologic response units (HRUs), Ponds/wetlands, Groundwater etc for each sub-catchment and the main reach draining into each sub catchment". The water balance equation is used for deriving the hydrologic cycle of SWAT model. It considers the unsaturated zone and shallow aquifer above impermeable layer. Shimaa M et al 2015 gave us SWAT equation for prediction of the watershed of hydrology,

$$S_{Wt} = S_{Wo} + \Sigma_i^t (R_{day} - Q_{Surf} - E_a - w_{Seep} - Q_{gw})_i$$

SWAT model consists of SWAT CN and SWAT WB method. In this research work, the WXGEN (Weather Generator) model was prepared by using pcpSTAT.exe software. For this, meteorological data of Bhatsa sub basin is used as input information. For determination of precipitation distribution and computation of PET, Skewed distribution and Penman Montieth method were used respectively.

III. AIM AND OBJECTIVES

The main objective of the study is to investigate the hydrology of the Bhatsa sub-basin using Arc Swat Model. For fulfilling this objective, hydrologic data of Bhatsa basin was collected. Land use/Land cover data, DEM map, Soil map was extracted from GIS. Calibration and validation of model was done by using Arc SWAT model. Rainfall, Temperature, LU/LC, DEM data were used as input data for simulation of SWAT model.

IV. STUDY AREA

Ulhas river has major right tributary called as Bhatsa river basin which is an east flowing river in the Western Ghats. It is having area of 736.343km^2. 55.7% of the total catchment area of Ulhas had been accounted only by major right bank tributaries i.e. Kalu and Bhatsa. Study area has maximum temperature ranging from 28.0˚C to 35.2˚C and the minimum temperature ranging from 16.3˚C to 26.5˚C. The annual average rainfall of the Bhatsa river basin is 2000 to 4000 mm from the South-West monsoons. It will occur during the months of June to September. Generally highest rainfall is recorded in the month of July. The study area lies Between 18°42' and 20°20' North latitudes and 72°45' to 73°48' East longitudes in eastern part of the state. Fig 1 shows the location map of the study area. Earth fill and gravity Bhatsa dam is located on Bhatsa river near Shahapur, Thane. Height of the dam above lowest foundation is 88.5 m (290 ft) while length is 959 m (3146 ft).Gross capacity is 976150.00km^3. Bhatsa reservoir is one of the major sources of distribution of drinking water. Reservoir storage is also used for irrigation, generation of hydroelectricity and for the industrial purpose. Fig 2 shows the location map of hydro meteorological stations. Input parameters which are used in SWAT are mentioned in Table 1.

Table 1 Input parameters of location of hydro meteorological stations

SITE NO	SITE NAME	LAT	LONG	HEIGHT
k329959	Kothale	19.580	73.565	302 m
N329956	Nadgaon	19.412	73.365	54 m

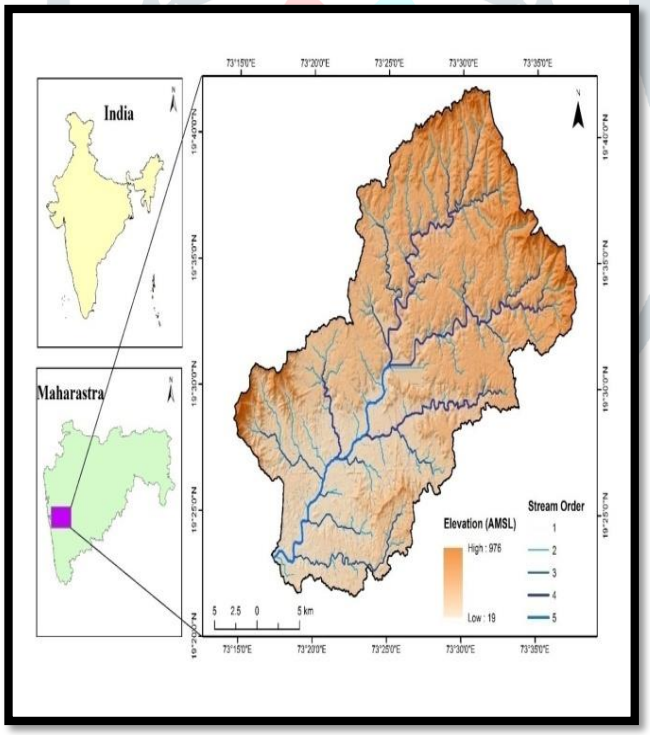


Figure1 Location Map of Bhatsa Dam
(Source: ArcGIS)

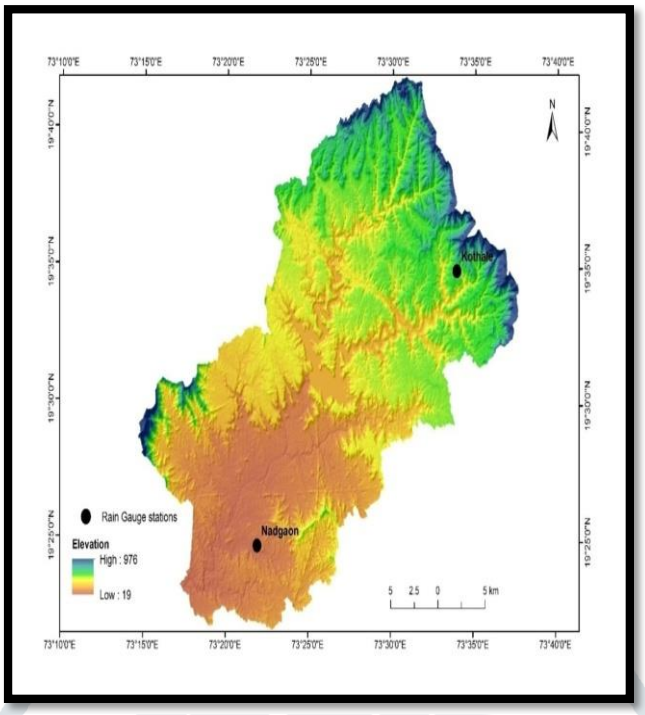


Figure 2 Location Map of Hydro-Meteorological stations

V. METHODOLOGY

A. INPUT DATA REQUIREMENT

DEM (Digital Elevation model)(Source: CGIAR-CSI DEM 30m x 30m resolution, Shuttle Radar Topography Mission; SRTM).This is used to determine the elevation of any point at any location in digital form. Digital elevation model of 1:50000 and 30m X 30m resolution was obtained from SRTM in tiles form. These tiles are then mosaicked in a single map. Shape file of Bhatsa river basin was created and was mosaicked in single map to derive actual DEM of Bhatsa river basin.

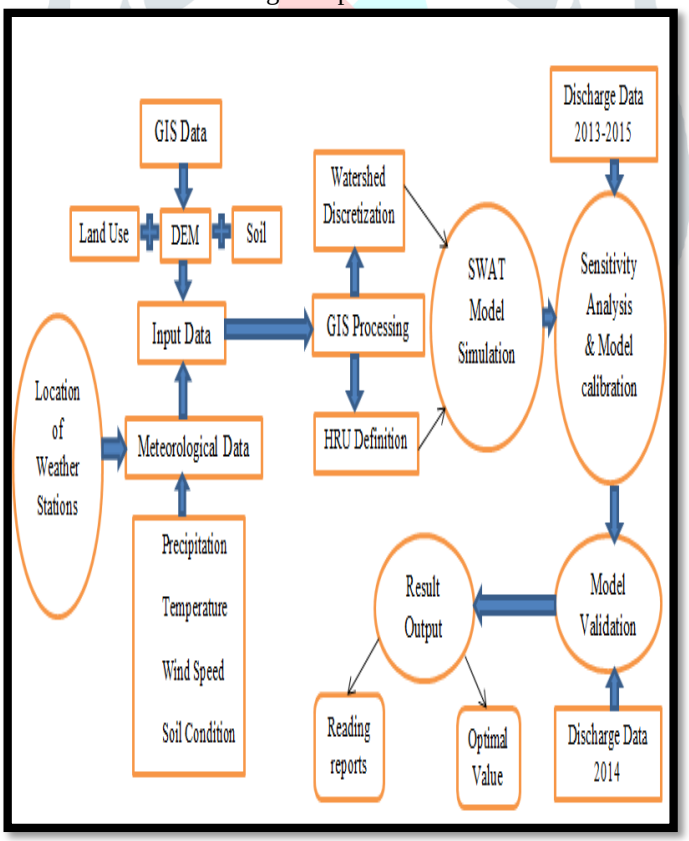


Figure 3 SWAT model Flow Diagram (Source: Shimaa M et al 2015)

Land use /Land cover data (Source: Landsat 8 OLI image) It gives idea about how much area had undergone under development, conservation or any other purposes etc as well as % of area is covered by forests, agriculture, barren land, residential area etc. Lu/Lc data was obtained from Landsat 8 OLI image. Unsupervised classification technique is used to classify the present land use and land cover. Fig 4 shows the LU/LC of the study area. From the Fig.4 it is concluded that study area is composed of max agricultural land (36.47% of the total area i.e. 26853.9279 ha).

Soil Data {Source: Arc SWAT (SWAT2012.mdb) for User soil data, MWSWAT (mwswat 2012.mdb) for Non US soil data}Availability of soil can be given by soil data. US soil database is already included in User soil table in Arc SWAT in

default manner. MWSWAT soil database which gives world soil database is then copied to Arc SWAT for the analysis purpose. It can be found that Loamy sand of about 53.07% of the total study area and loamy silt of about 46.93% of the total study area are found. Fig 5 shows the Soil texture of the study area.

Slope Data Slope helps to find out the Hydrological response Unit in SWAT model. Bhatsa river basin varies from 0 to 72.115 degrees slope values. Fig 6 shows the slope of the study area.

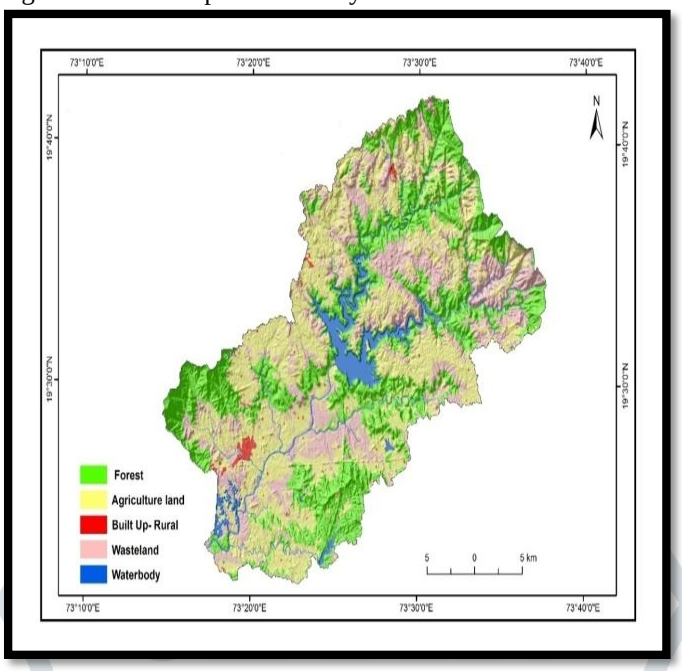


Figure 4 Land Use/Land Cover of the Study Area

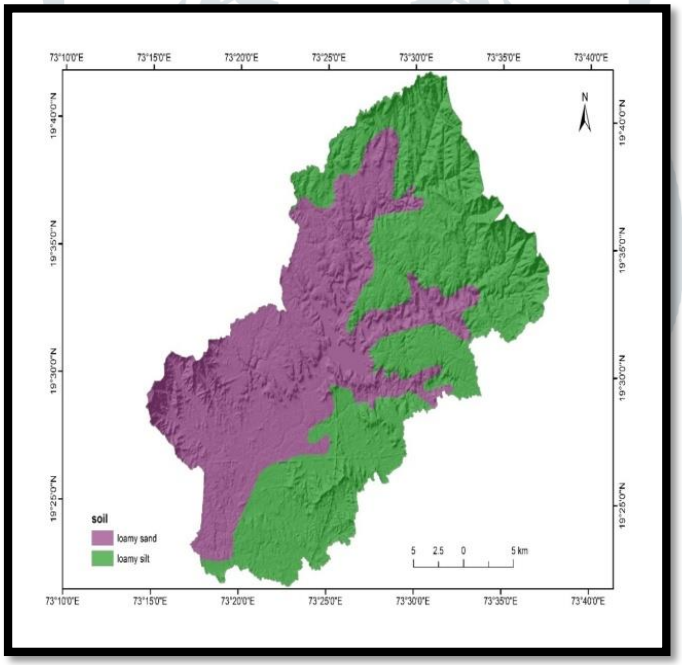


Figure 5 Soil texture of the study area

VI. MODEL SETUP

Basically SWAT model comprises into five processes; Project setup, Watershed Delineation, HRU analysis, writing input tables for SWAT, SWAT output, SWAT simulation.

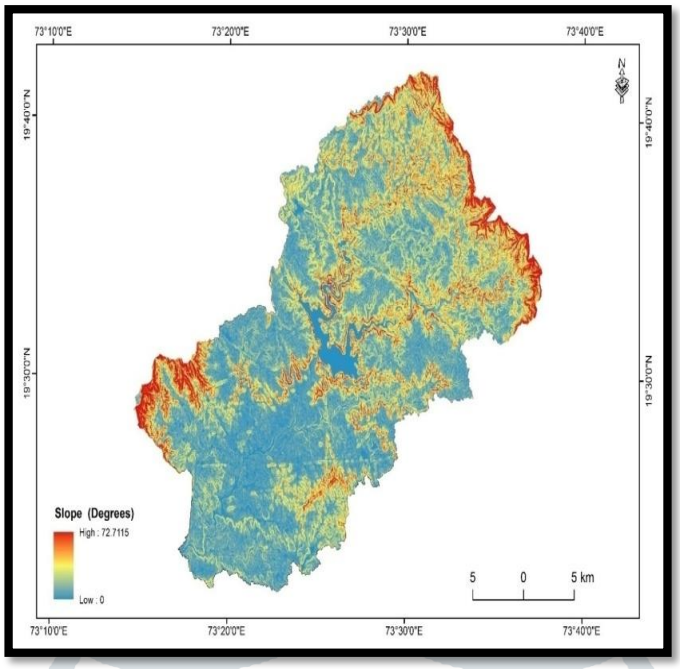


Figure 6 Slope of the study area

A Project Setup and Watershed Delineation

Project setup was done by saving SWAT project in proper dictionary. After completing project setup, Automatic watershed delineation was done by introducing DEM map. Flow direction and Flow accumulation was created by skipping mask and burn in option. It gave us critical stream area network. In this study finally the watersheds were delineated to be 736.343KM^2 Bhatsa watershed. After creating Flow direction and Flow accumulation, Sub basins, outlets, stream network is to be found out. Total 27 sub basins are generated for the given Bhatsa watershed.

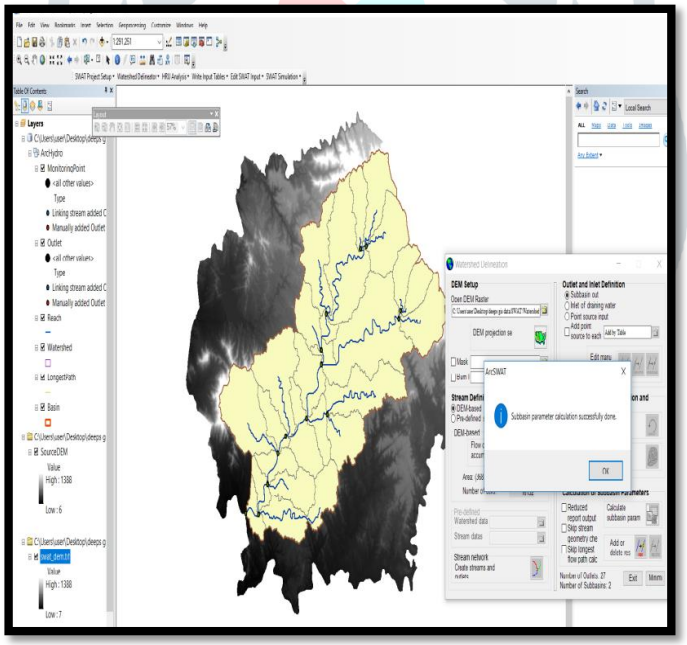


Figure 7 Water delineation (Source: Arc SWAT)

B Hydrological Response Unit (HRU)

After delineation is over, Land use and Land cover data, Soil data, Slope data will be prepared in table. This HRU table can be further added in existing DEM map. The land use and soil map was overlapped 100% with the delineated watershed. 272 HRUs for Bhatsa watershed were created for 27 sub basins.

C Writing Input tables

After georeferencing was done, weather data such as Precipitation, temperature etc was edited. Precipitation was taken on daily scale. No of Rain gauges were also added.

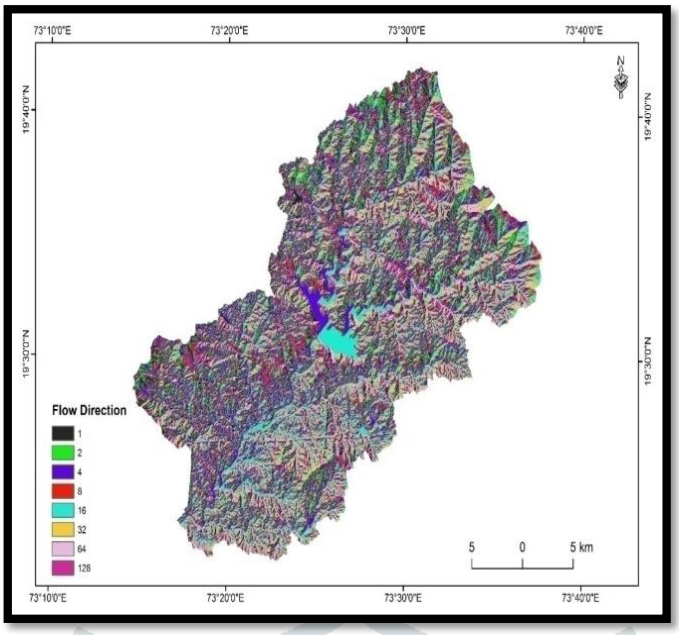


Figure 8 Flow direction grid of the study area

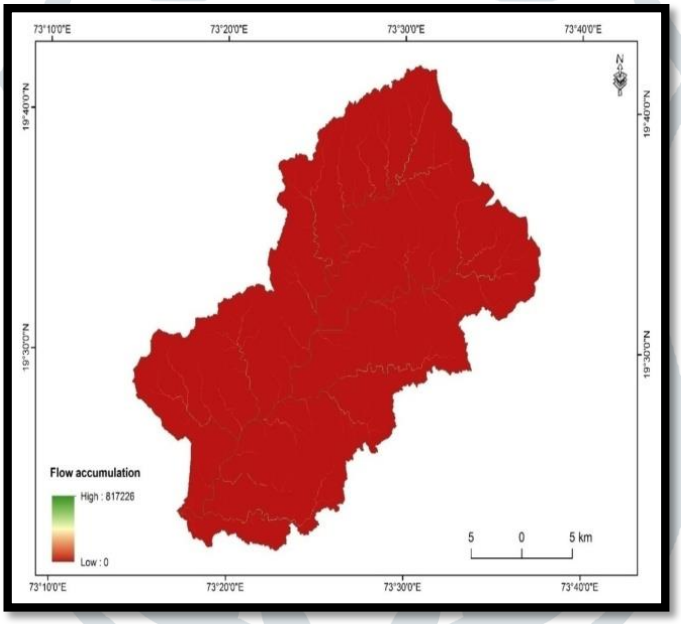


Figure 9 Flow accumulation grid of the study area

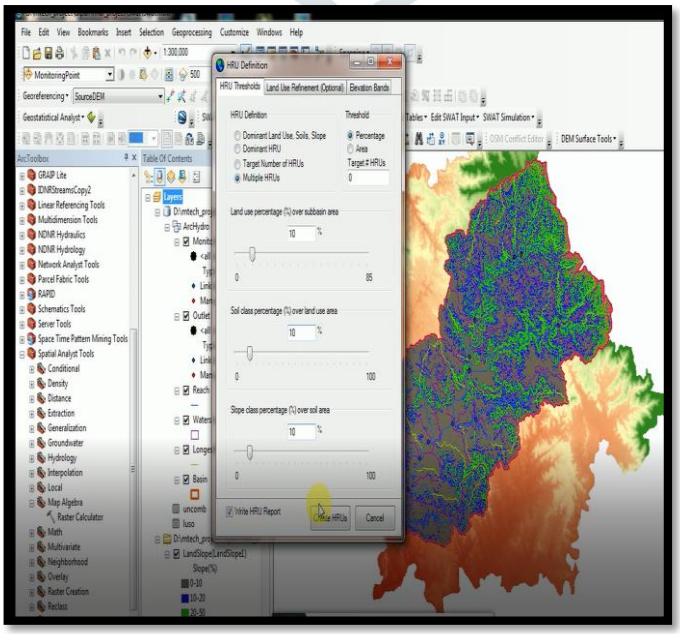
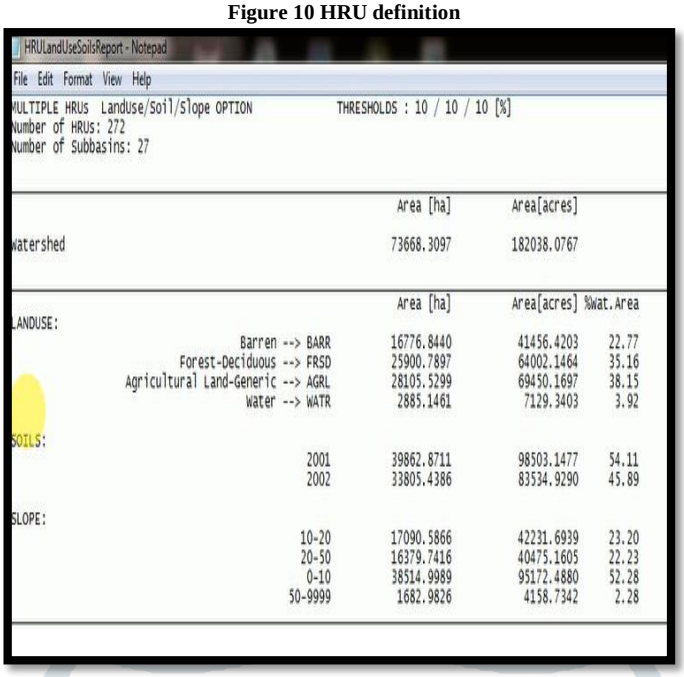


Figure 10 HRU definition



HRULandUseSoilsReport - Notepad

File Edit Format View Help

MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 10 / 10 / 10 [%]
Number of HRUs: 272
Number of Subbasins: 27

	Area [ha]	Area[acres]	
Watershed	73668.3097	182038.0767	
	Area [ha]	Area[acres]	%Wat.Area
LANDUSE:			
Barren --> BARR	16776.8440	41456.4203	22.77
Forest-Deciduous --> FRSD	25900.7897	64002.1464	35.16
Agricultural Land-Generic --> AGRL	28105.5299	69450.1697	38.15
Water --> WATR	2885.1461	7129.3403	3.92
SOILS:			
2001	39862.8711	98503.1477	54.11
2002	33805.4386	83534.9290	45.89
SLOPE:			
10-20	17090.5866	42231.6939	23.20
20-50	16379.7416	40475.1605	22.23
0-10	38514.9989	95172.4880	52.28
50-9999	1682.9826	4158.7342	2.28

Figure 11 HRU analysis report

D.SWAT Simulation

Once all SWAT inputs have done, click on SWAT simulation- Run SWAT. Set period of simulation

VII. CALIBRATION AND VALIDATION

In present study, the calibration period has been selected from 2013 to 2015. For this, the same type of variables and criteria is used for calibration and validation. The validation period has been chosen as 2014. Sensitivity analysis which is based on entire flow parameters is carried out in Bhatsa river basin, to improve the efficiency of the model. After auto calibration, Soil evaporation compensation factor (ESCO) and initial SCS curve number II value (CN2) were two sensitive parameters adjusted to improve the efficiency of model.

VIII. EFFICIENCY OF MODEL

Efficiency of model can be found by using Coefficient of determination (r^2) and Nash Sutcliffe Efficiency (NSE). According to Shimaa et al 2015, Coefficient of determination gives good evaluation performance between observed and simulated data. When r^2 value is greater than 0.5, it indicates that model has acceptable efficiency range. (Shimaa et al 2015). This can be calculated by using following equation,

$$r^2 = \frac{\sum_{i=1}^{n}(Q_{si} - Q_{sm})(Q_{oi} - Q_{om})^2}{\sum_{i=1}^{n}(Q_{si} - Q_{sm})^2 \sum_{i=1}^{n}(Q_{oi} - Q_{om})^2}$$

According to Nash et al 1970, performance criteria assessment (Nash Sutcliffe Efficiency) in SWAT can be easily found out by using following equation,

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi} - Q_{om})^2}$$

NSE value varies from ∞ to 1. When NSE value is more than 0.5, it gives satisfactory result.

Table 2 Performance assessment criteria's SWAT

Performance Evaluation	NSE
Very good	0.75 < NS ≤ 1.00
Good	0.65 < NS ≤ 0.75
Satisfactory	0.50 < NS ≤ 0.65
Unsatisfactory	NS ≤ 0.50

IX. RESULT AND DISCUSSION

In Fig 5.1, Graph of observed data and simulated data for given simulated year (2013-2015) is shown. It is observed that simulated discharge has increased in the year 2013 (9.7 cm^3) and also found unclear increment in year 2014 (10 cm^3). It is found in month from March to April of 2013, Stream flow has been increased at value of 7.5 cm^3 and 6 cm^3 respectively. Excepting these values, simulated discharge occurs in the month of July to Sept of each year. Figure indicates irregular flows throughout the year. Fig 5.2shows graph of observed value vs. simulated stream flow value. It gives coefficient of determination (r^2) value as 0.355 which indicates non linear relationship between the observed and simulated stream flow values. Hence, model is needed to be calibrated. This can be done manually by editing SWAT input parameters. Sensitivity parameters such as ESCO (Soil evaporation compensation factor) and initial SCS curve no II value were adjusted. For better efficiency, calibrated model was validated for year 2014.

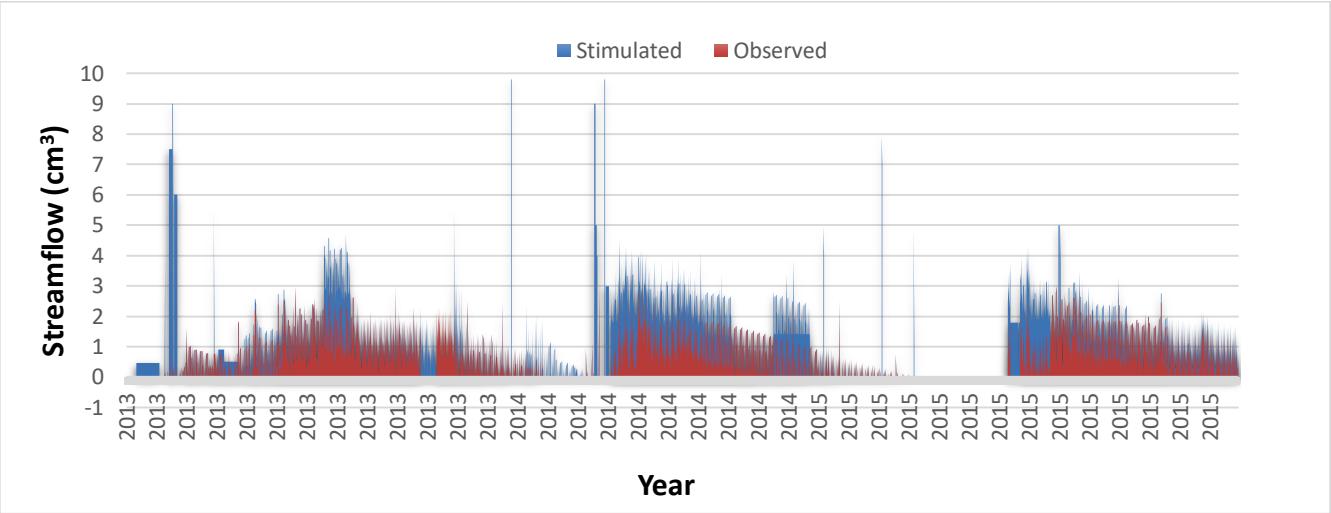


Figure 12 Graph of stream flow vs. year (Before Calibration)

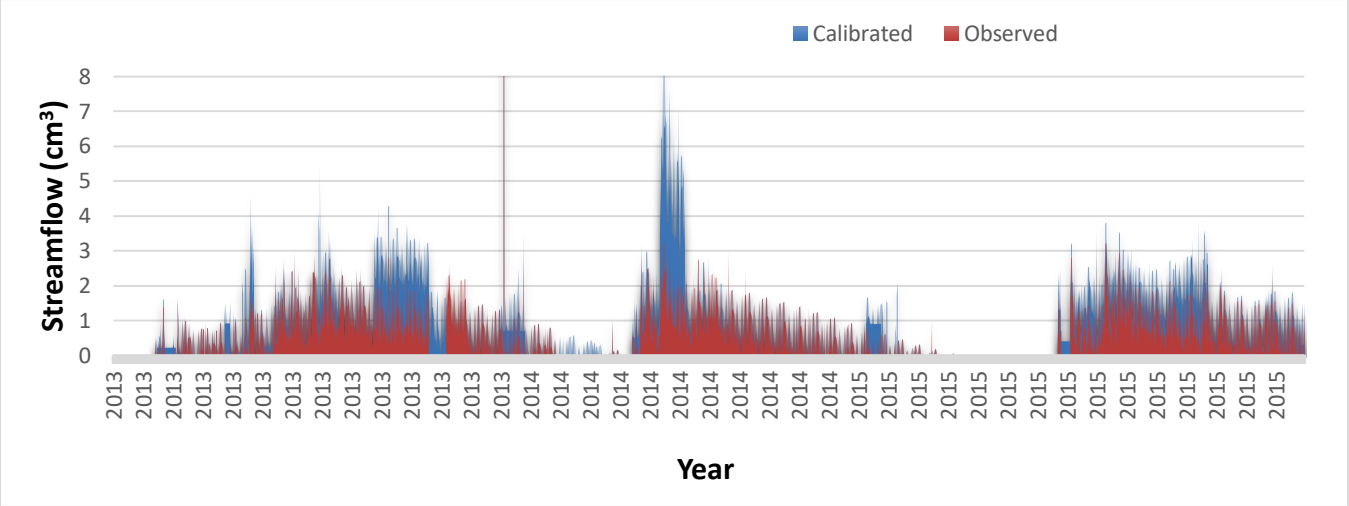


Figure 13 Graph of Stream flow vs. year (calibrated)

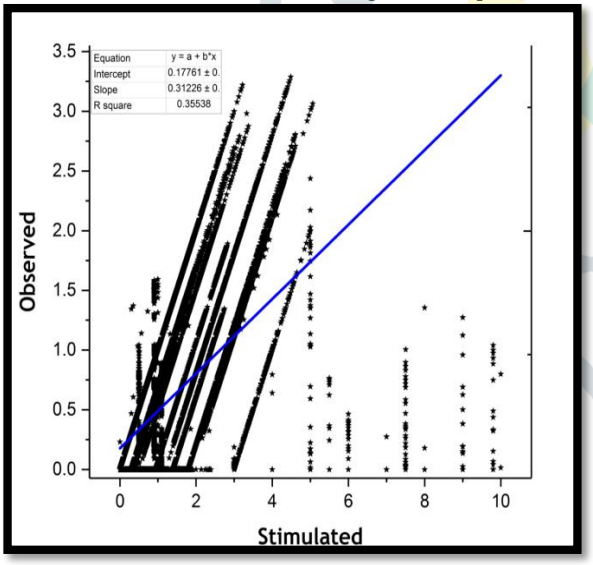


Figure 14 Graph of stimulated stream flow vs. Observed stream flow (Before Calibration)

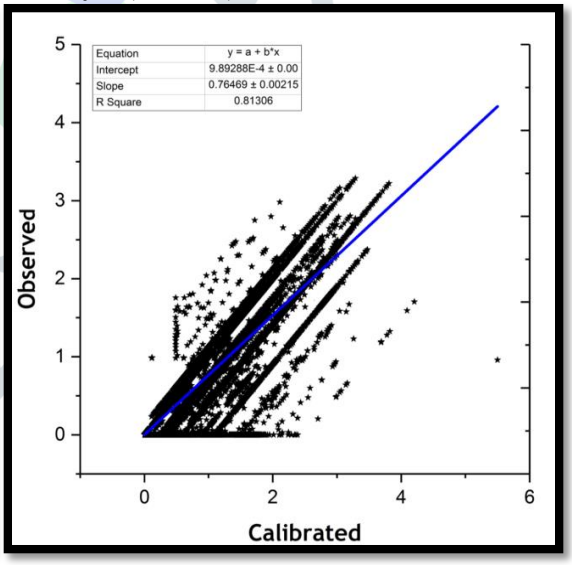


Figure 15 Graph of calibrated Stream flow vs. Observed stream flow

X. CONCLUSION

The hydrological modelling of Bhatsa watershed, Shahapur, Thane has been successfully done by Arc SWAT. Input parameters like GIS data and Meteorological data were collected from various sources. GIS data includes DEM which was taken from SRTM, Lu/Lc data was extracted from Landsat 8 OLI image etc. Meteorological data includes Rainfall, Temperature, Solar radiation, wind speed, Humidity etc which was collected from Bhatsa office, Shahapur, Thane. Surface runoff is found by using SWAT-CN method. This data was reassembled in WXGEN user table which is based on SWAT-WB method. Watershed delineation was done by performing stream definition, calculation of sub basin parameters and Watershed definition. From this, we got 2 no of outlets and 27 no of sub basins. Simulation was done by following HRU analysis, Input tables, SWAT simulation, and SWAT output. The Skewed distribution and Penman Montieth method was selected for estimation of potential evapo-transpiration for adjustment of mass balance components.Flow calibration and validation were done based on the observed flow

data which is collected at Kothale and Nadgaon rainguage stations at the Bhatsa basin. For testing efficiency of simulation model, the predicted results were compared by using the available measurements. Simulated results were found to be irregular manner. It happens because of insufficient input parameters of model. Value of R^2 i.e. coefficient of determination of simulated model is found to be 0.355. As per the performance criteria, if R^2 value is greater than 0.5 then it is considered as acceptable limit. In this work, calculated value is less than 0.5. Hence, Calibration was needed. It took place by editing the SWAT input files for the period from 2013 to 2015. Nash Sutcliffe efficiency was found to be 0.71 for the calibration period which indicates satisfactory result. For getting better result, sensitivity analysis was done on the evaporation soil compensation factor (ESCO) and initial SCS curve number II value (CN2). Further this calibrated model is validated for period of 2014.and got Nash Sutcliffe efficiency as 0.735. As per performance assessment criteria in SWAT, if the value is between 0.65 to 0.75, model is considered has good performance criteria.

From the validated results, it is concluded that model is ready to apply on the watershed to determine the daily surface runoff. This runoff is further managed properly which is used for overcoming the problem of water management in Study area. Bhatsa river basin is one of the major distribution source which is used for drinking water, irrigation, industrial and electricity generation purpose. It supplies max amount of water from nearby rural areas to highly urbanized areas. Hence, management of the source in the given study area is necessary. Max rainfall occurs only from July to September month which do not contribute the required amount of water and always tend to face the deficiency of water problem. Arc SWAT gave the satisfactory results. Hence methodology in the present study can be applied to determine the daily runoff in Indian basins by using Arc SWAT.

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