Determination of Water Budget of the Lower Godavari River Basin Using GIS and SWAT

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Abstract - To study the hydrological cycle, water budget components are very important. Water budget also helps us to identify periods of deficit and excess rainfall and calculate the availability of water at any given time. Water budget components include precipitation, base flow, evapotranspiration, change in terrestrial water storage (which include both subsurface and surface water storage) and surface run off. This paper depicts how these water budget components can be estimated using Geographical Information System (GIS) and Soil and Water Assessment Tool (SWAT). The study area selected for this purpose was the entire Lower Godavari Basin, India. SWAT inputs such as Digital Elevation Model (DEM), Land Use/Land Cover (LU/LC), soil classification, slope and weather data was used and water budget components were obtained as output and analyzed. The simulated data obtained was then compared with the observed data and coefficient of determination, R^2 between the simulated data and observed data was found to be very high, which validated the results.

Keywords - Digital Elevation Model (DEM), Evapotranspiration, Land Use/Land Cover (LU/LC), Soil and Water Assessment Tool (SWAT), Water Budget, Coefficient of determination.

I. INTRODUCTION

Water is very precious, its presence affects how and where plants and animals exist on earth. All life forms require water and due to increasing population there is a competition for water among humans as well as between humans and other life forms. To resolve these problems decisions based on science and social values need to be taken, hence study of hydrological cycle becomes very important. [1]

Hydrological cycle refers to the continuous circulation of water and includes processes like evapotranspiration from the surfaces of seas, lakes, leaves, etc which gets stored in the form of clouds and when these clouds become heavier and denser, condensation occurs and water comes back to the land or oceans in the form of liquid or snow [2]. The relation between the input and output of water in a region, such as a watershed, is called water budget.

Water budget helps us to evaluate water supply, its sustainability and availability. The rate with which the water flows in and out of the given area and rate of change in stored water, balance each other. Water budget also helps us to identify periods of deficit and excess rainfall and calculate the availability of water at any given time [1]. Most important components of water budget include precipitation, runoff, base flow, change in water storage and evapotranspiration. [3]

The study area selected was the entire Lower Godavari Basin and the software used for the determination of budgeting components is Soil and Water Assessment Tool (SWAT). GIS as used for getting various SWAT input data such as DEM, LU/LC and soil data. [4]

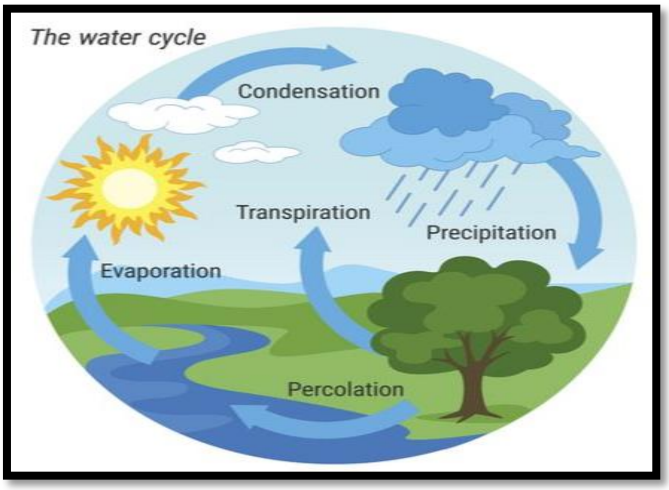

Fig 1: Water cycle (Source: worldatlas.com)

II. LITERATURE REVIEW

A detailed literature survey was carried out which showed that GIS and remote sensing in water balance study is very helpful in determining the periods of moisture surplus and moisture deficit for a basin. The technique involved use of average potential evapotranspiration, average monthly rainfall and vegetation and soil characteristics. Rovick P. Tarife and Anacita P.(2017) [5] performed hydrological modeling based on GIS data on raster cells to identify and classify the hydropower potential sites in Misamis Occidental in the Philippines. Input data included DEM,

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watershed boundary, LU/LC, soil maps and weather data. Mercy C Cheruto and Matheaus K Kauti (2016) [6] used ERDAS imagine to detect LU/LC changes using satellite data obtained from LANDSAT 7. Sene, (2013) [7] measured rainfall using radar weather stations rather than from rain gauges as they give higher temporal and spatial resolution. Du and Sun, (2012) [8] calculated ET in ungauged basins using Ts/NDVI space combined with Priestley-Taylor equation, MODIS NDVI data and (GLDAS) meteorological data. Xiang et al. (2012) [2] estimated runoff data using TRMM precipitation data by a distributed hydrological model in Xinjiang catchment, Poyang lake basin. Kuss et al. (2011) [9] considered three methods to derive groundwater storage estimates. In first directly GRACE derived groundwater data was compared to in-situ groundwater levels. In second method water budget was calculated to check GRACE TWS value and third method included calculation of GRACE TWS value and comparing it with the hydrological model. Venturini et al., (2008) [10] used Granger's complementary relationship and Priestley-Taylor equation to derive ET from satellite data without site-specific relationships. Islam and Uyeda, (2007) [11] determined the climatic characteristics of rainfall in Bangladesh using Tropical Rainfall Measuring Mission (TRMM) data. Post-monsoon, monsoon and pre-monsoon season was studied by taking ground based rainfall data as base. Mu et al., (2007) [12] developed MODIS global ET. Tasumi et al., (2003) [13] computed soil heat flux by dividing the area into sub-area by selecting hottest and coldest pixel for each to derive the ET.

III. OBJECTIVE

The objective is to find the water budget components like precipitation, runoff and evapotranspiration of the Lower Godavari basin from satellite data and hydrological modeling using SWAT and validate it by comparing it with the observed data by finding the coefficient of determination between them.

IV. STUDY AREA

The Godavari river is the longest river in the Indian peninsula and is the second longest river after the Ganga in India. It extends from longitudes 76° to 83° east and latitudes 17° to 23° north. Its starts in Triambakeshwar, Maharashtra and flows eastwards to end into the Bay of Bengal. It spans over 1,465 kilometers in length passes through Maharashtra, Andhra Pradesh, Telangana, Madhya Pradesh, Chhattisgarh, Karnataka and Puducherry. It forms the largest river basins in the Indian subcontinent, measuring upto 312,812 km^2 after Indus and Ganga River and because of this it is often also called as the Dakshina Ganga. [14]

The river basin is divided into three main sections: Upper (from the source to Manjira), middle (between Manjira and Pranhita) and lower (from Pranhita to mouth). For this research we have selected the entire lower Godavari basin. Lower Godavari has a total catchment area of 24869 kilometer square and length of 462 kilometers. The elevation of the source is at 107 MSL and the basin receives an average rainfall of 1208 millimeters. The lower basin is dominated by the Eastern Ghats and is mainly formed from the khondalites and Rajahmundry sandstones make up the coastal region. The major soils in the lower godavari basin are red soil and black soil and forest covers area greater than 50%. Three major reservoirs namely Balimela, Machkundjalaput and Upper Kolab were also considered. Figure 2 shows the map of the lower Godavari basin, which is selected for the study.

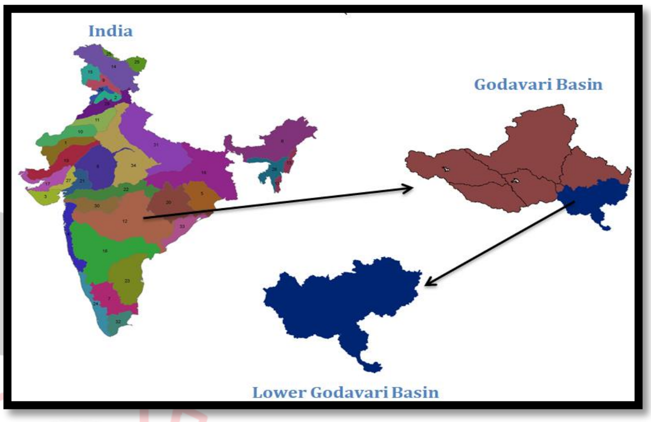

Figure 2: Study Area (Lower Godavari basin)

V. METHODOLOGY

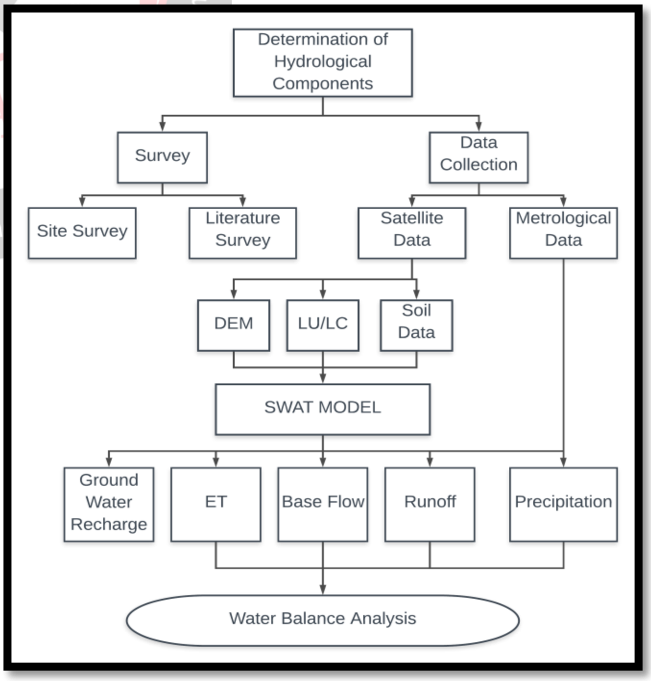

Figure 3: Flow chart of methodology

The methodology adopted for the water budgeting approach is described in the form of a flowchart in Figure 3. First for the base map DEM was prepared using data downloaded from the USGS earth explorer. SRTM 1 Arc-Second Global data for the Lower Godavari basin was downloaded [15].

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The decadal landuse/landcover data for the entire India at 100 m resolution at intervals 1985, 1995 and 2005 was gathered from the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC). This data was derived from Landsat 4 & 5 Thematic Mapper (TM), and Multispectral (MSS) data and Enhanced Thematic Mapper Plus (ETM+), Indian Remote Sensing satellites (IRS) Resourcesat Linear Imaging Self-Scanning Sensor-1 or III (LISS-I, LISS-III) data, visual interpretation and ground truth surveys. Soil map information was gathered from India dataset provided in the official SWAT website by Dr. Balaji Narasimhan. This DEM, LU/LC, soil Map was used as input to run the SWAT.

After successful SWAT run, water budget components such as precipitation, runoff, evapotranspiration, base flow and ground water recharge were obtained. Precipitation data for the Lower Godavari Basin was also obtained from India WRIS and compared with data precipitation data obtained from SWAT. The coefficient of determination, R^2 between them was found to be very high and hence validated the result.

VI. THEMATIC MAPS

Maps which depict a specific subject or a theme are called thematic maps. Below are different thematic maps of the Lower Godavari basin obtained from ArcSWAT.

A. Landuse/Landcover

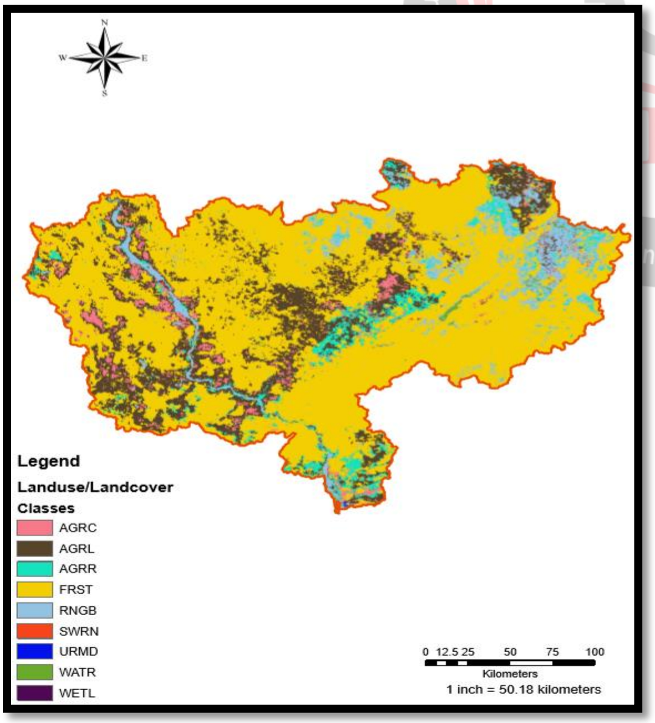

Figure. 4 landuse/landcover map of lower Godavari basin

Figure 4 shows the landuse/landcover distribution for the Lower Godavari basin. Where AGRC is Agricultural Land-Close-grown, AGRL is Agricultural Land-Generic, AGRR is Agricultural Land-Row Crops, FRST is Forest, RNGB is Rangeland Brush, SWRN is South Western Arid Range, URMD is Urban Residential Medium Density, WATR is Water and WETL is Wetland.

B. Soil Map

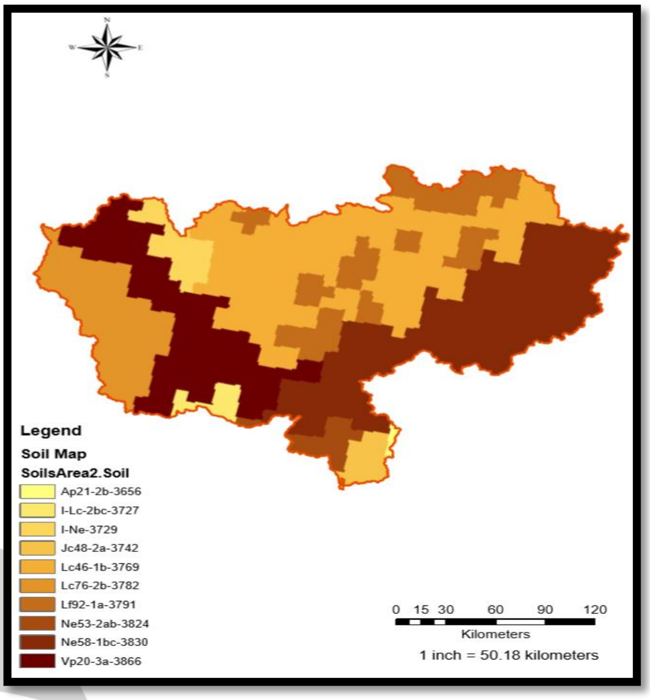

Figure 5 Soil map of lower Godavari basin

Figure 5 shows the soil map of the Lower Godavari basin. Soils in Lower Godavari basin is dominated by sandy clay loam, loam, clay loam, sandy loam and clay. Table 1 shows the main soil taxonomy of the above soil map.

Table 1

Soil map of lower Godavari basin

Ap21-2b-3656	SANDY_CLAY_LOAM
I-Lc-2bc-3727	LOAM
I-Ne-3729	LOAM
Jc48-2a-3742	CLAY_LOAM
Lc46-1b-3769	SANDY_CLAY_LOAM
Lc76-2b-3782	CLAY_LOAM
Lf92-1a-3791	SANDY_LOAM
Ne53-2ab-3824	SANDY_CLAY_LOAM
Ne58-1bc-3830	SANDY_CLAY_LOAM
Vp20-3a-3866	CLAY

C. Digital Elevation Model

Figure 7 show the digital elevation map of the lower Godavari basin. It is 1 arc second SRTM data, taken from USGS earth explorer.

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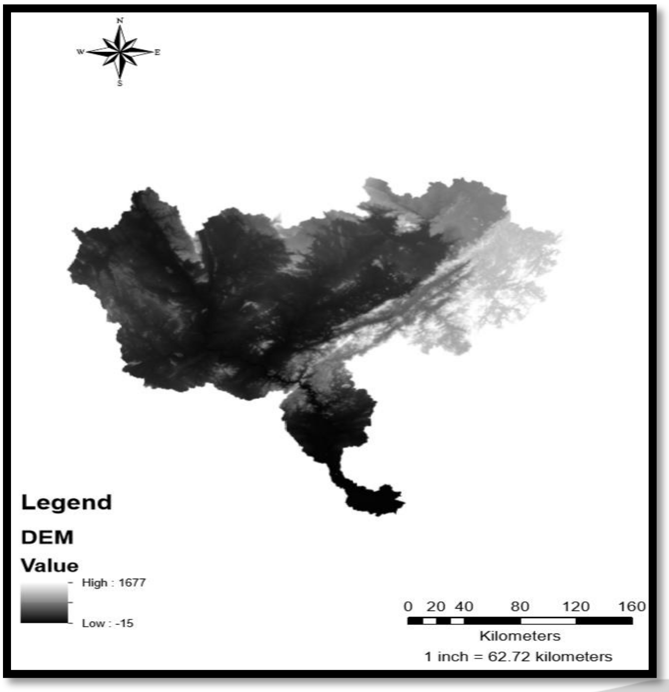

Figure 7 Digital elevation of lower Godavari basin

VII. SWAT MODEL

SWAT stands for Soil and Water Assessment Tool. It is a watershed to basin scale model that helps us find the water budgeting components using the input dataset. It helps us simulate and hence manage the quality and quantity of ground as well as surface water. Figure 8 is the flowchart showing the SWAT model.

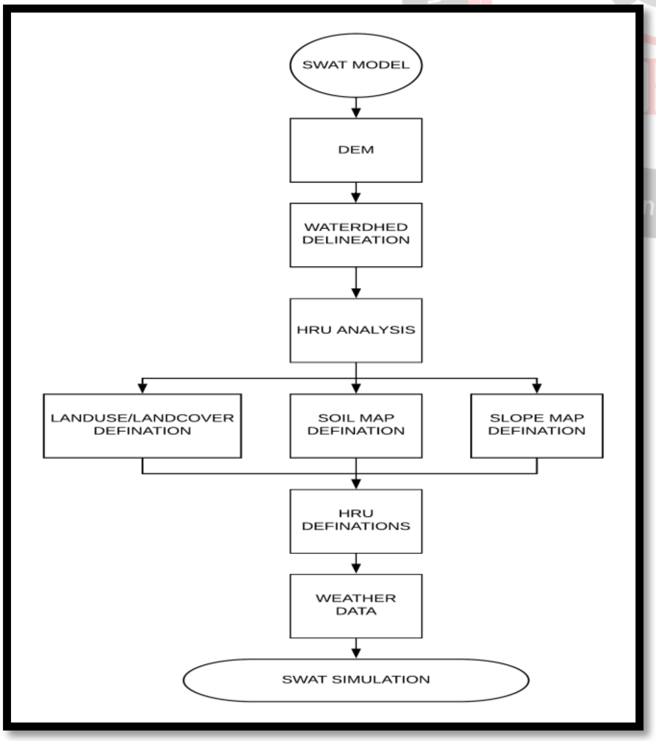

Figure 8 Flow Chart of SWAT model

In SWAT, first we have to setup new project and start with automatic watershed delineation. In automatic watershed delineation first we have to input the DEM and then perform the flow direction and accumulation. After which we have to create stream network. Once the stream network is created, we need to select an outlet through which the entire water from the basin pours out. Then finally watershed delineation is done after which sub-basin parameters are found out. After watershed delineation, HRU analysis is performed. In HRU analysis, landuse/landcover data, soil data and slope data is defined and overlaid together over the DEM. After HRU analysis, weather stations are input and SWAT simulation is run. After successful SWAT run, the water budget components where obtained as a result.

VIII. RESULTS AND CONCLUSION

SWAT model simulation gave us the water budgeting components which when compared to the actual data were similar. Main equation of water balance can be written as:

P − ET – Q – Base flow ± ΔTWS - (other components) = 0 (Equation 1)

Where, P = Precipitation, E = Evapotranspiration , Q = Runoff, ΔTWS=Change in Terrestrial Water Storage and other components include deep and shallow ground water storage, interception, soil moisture, glaciers and snow, etc. [1]

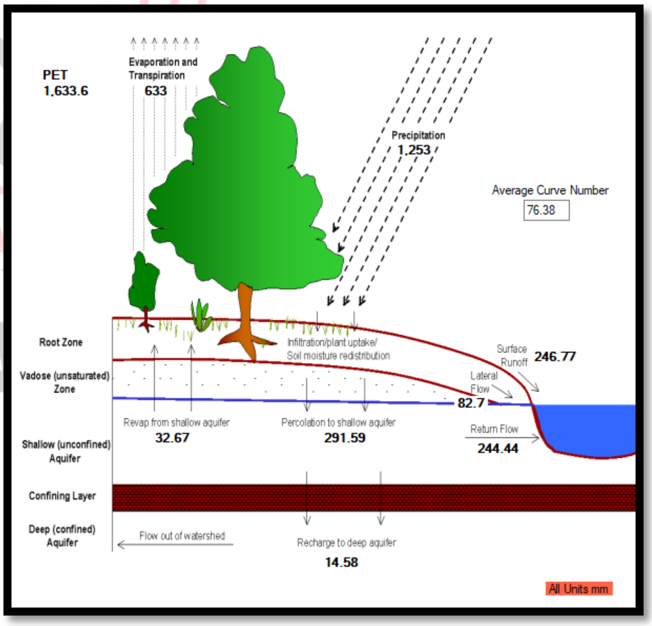

Figure 9 Water budget components of lower Godavari basin

Figure 9 shows the SWAT outputs as water budget components. The output showed that the average precipitation in the lower Godavari basin is 1253 millimeter, the average total runoff (surface, lateral and return) is 573.91 mm, average groundwater recharge is 14.58 mm and average evapotranspiration is 633 mm.

Therefore, from equation 1:

1253 - 573.91 - 633 - 14.58 – 31.51 = 0

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This **31.51** is due to other components which include deep and shallow ground water storage, interception, soil moisture, glaciers and snow, etc.

The water balance is equal to zero means that the amount of water that is entering the lower Godavari basin is equal to the amount of water leaving it, as shown in the Table 1, and hence the water cycle is complete. Now we can record the amount of water deposited, water withdrawn and balance water available.

Table 1 Water Budget Components

Water Budget Components	**Incoming (mm)**	**Outgoing (mm)**
Precipitation	1253	-
Evapotranspiration	-	633
Runoff	-	573.91
Ground Water Recharge	-	14.58
Other Components	-	31.51
Total	**1253**	**1253**

Figure 10, 11, 12 and 13 shows the average monthly precipitation, runoff, ET and water yield in the form of graphical representation.

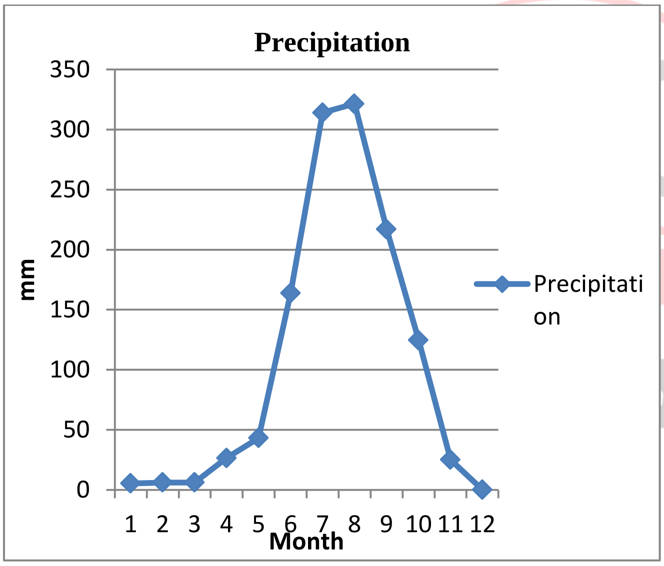

Fig. 10 Average monthly rainfall for lower Godavari basin

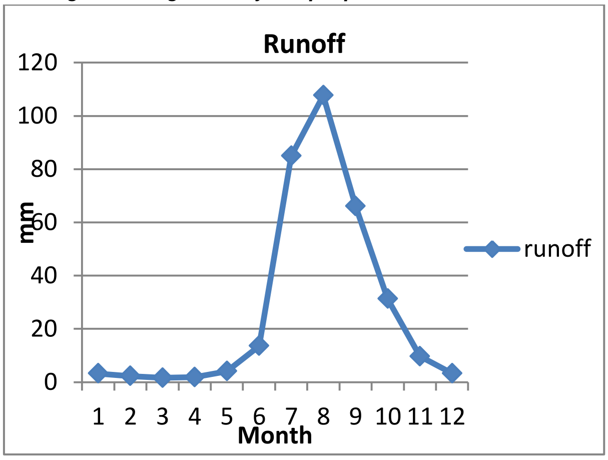

Fig. 11 Average monthly runoff for lower Godavari basin

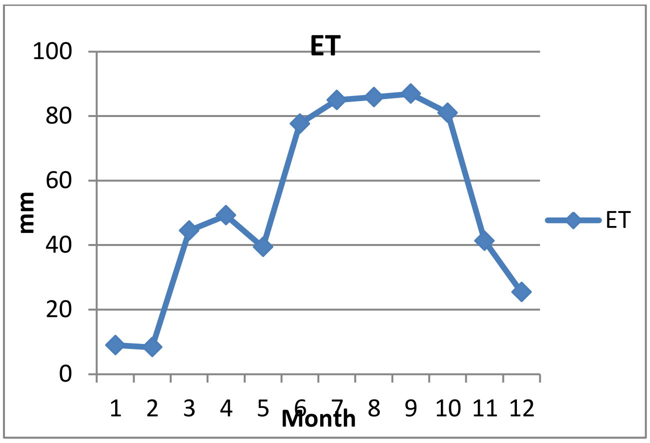

Fig. 12 Average monthly evapotranspiration for lower Godavari basin

Average monthly values of precipitation, runoff, ET and water yield of the lower Godavari basin is shown in table 2.

Table 2
Average monthly values

Month	Precipitation	Runoff	ET	Water Yield
1	5.34	3.26	8.95	7.46
2	6.11	2.25	8.31	3.34
3	6.04	1.61	44.48	2.54
4	26.45	1.83	49.21	2.45
5	43.11	4.09	39.36	4.43
6	163.78	13.56	77.63	13.01
7	314.04	84.95	84.96	86.53
8	321.47	107.68	85.85	146.42
9	217.16	66.08	86.91	140.37
10	124.76	31.28	80.98	102.02
11	24.95	9.67	41.29	54.81
12	0.13	3.31	25.4	25.24

The water yield is the amount of water available for use and is the difference between the amount of precipitation and evapotranspiration. This water can be used for various irrigational, household and industrial purposes. [16]

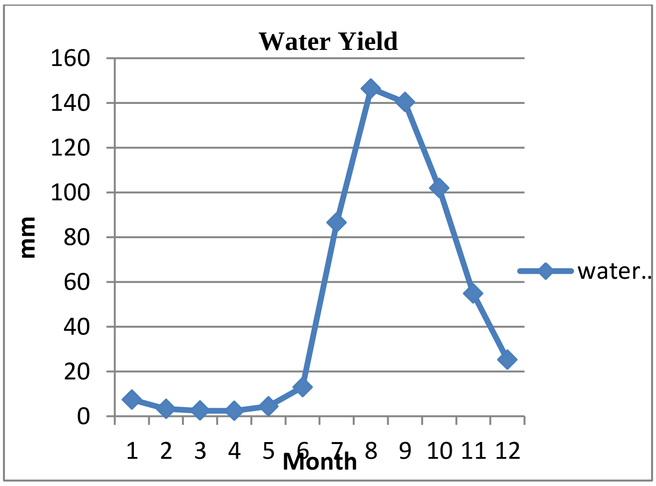

Fig. 13 Average monthly water yield for lower Godavari basin

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Validation

For validation of results, monthly average Precipitation data for the Lower Godavari Basin was obtained from the India WRIS. For comparison of this data regression analysis was performed and the Coefficient of Determinacy, R^2 was found out. Coefficient of Determinacy is the square of the correlation, R between the observed and calculated data and hence its value is between 0 and 1 [17]. Greater the value, i.e. the closer the value is to 1, higher is the similarity and the lower the value, i.e. the closer the value is to 0, lesser is the similarity between the datasets. [18]

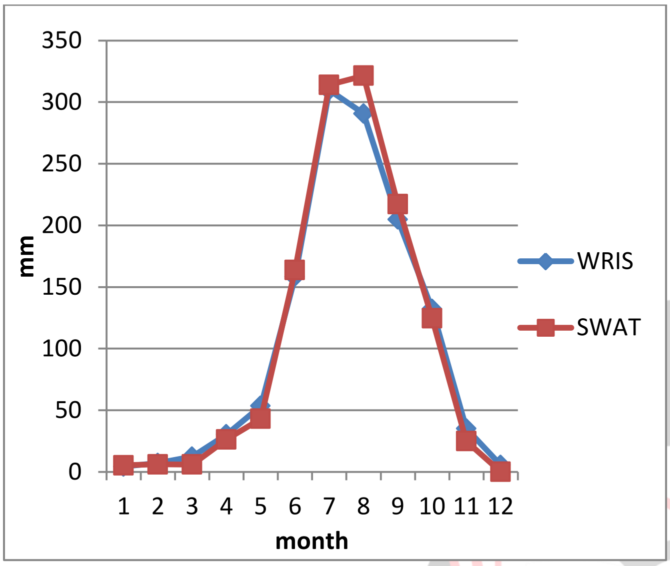

Figure 14: Comparison of average rainfall in the Lower Godavari Basin from SWAT and India WRIS

Comparison between the calculated values and the observed values of the average monthly precipitation data over the Lower Godavari Basin showed high degree of similarity and the value of coefficient of determinacy, R^2 between them was found to be 0.9953. Figure 14 shows the graph between the average monthly precipitation data of the lower Godavari basin obtained from SWAT and India WRIS.

Average monthly precipitation data of the lower Godavari basin obtained from SWAT and India WRIS is shown in table 3.

Table 3
Average monthly precipitation data of the lower Godavari basin obtained from SWAT and India WRIS

Month	WRIS	SWAT
January	4.4	5.34
February	7.18	6.11
March	12.36	6.04
April	30.46	26.45
May	53.46	43.11
June	158.35	163.78
July	309.64	314.04
August	290.7	321.47
September	204.83	217.16
October	132.17	124.76
November	35.22	24.95
December	5.59	0.13

Table 4 below shows the regression analysis results between the precipitation data.

Table 4
Regression Analysis output

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.997876711
R Square	0.99575793
Adjusted R Square	0.995333723
Standard Error	8.338045506
Observations	12

IX. CONCLUSION

The water budget components of the Lower Godavari Basin were found out using GIS and SWAT and validated using data from India WRIS. This data helps us to find the inflow and outflow of water in a particular region and also changes in the quantity of water. Hence it helps us to identify the periods of less or excess rainfall. It also helps us to find the availability of water at any given time and predict when there might shortage of water. Further research can be done to properly allocate the amount of water available in the lower Godavari basin for different purposes.

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