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Assessment of water balance for Arjuna river basin using ArcSWAT

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Abstract
The present investigation was to study water balance for Arjuna River basin of Ratnagiri District of the Maharashtra State using ArcSWAT model. The ArcSWAT model requires four type of dataset, viz. Land Use Land Cover (LULC), Soil, topographical and hydro-meteorological data for evaluating the hydrological processes. In the present study data were procured from various sources. ArcSWAT was utilized to simulate and analyze various components of the water balance within the Arjuna River basin. These components include evapotranspiration, surface runoff, baseflow and total precipitation. Each element plays a crucial role in understanding the hydrological dynamics and water availability in the area. The study found that the river flow during January to May and December in almost all basins is less than 1 cubic meter per second, indicating minimal groundwater contribution. Also groundwater availability in the Arjuna River basin is significant during August, September, October and November, primarily due to rainfall from June to September. The ArcSWAT model, calibrated from 1996 to 2003 and validated from 2007 to 2012, demonstrated robust performance, evidenced by satisfactory R^2 values (0.78 during calibration and 0.67 during validation) and Nash-Sutcliffe efficiency values (0.75 during calibration and 0.65 during validation).

Keywords: ArcSWAT, water balance, evapotranspiration, hydrological components

Introduction
Water and land are the most important essential resources for the crop production everywhere in the world. Plants need water for survival continuously during its life cycle and soil provides physical support and required nutrients. These resources are prime important for agriculture-based economies. India being an agrarian economy, where 54.6 per cent of the population directly depends on agriculture, is highly vulnerable to the impacts on water and land resources (Mehla *et al*., 2023) [14]. Rise in temperature, precipitation variation and its increased frequency of extreme events, land degradation ad sea water level rise have serious implications on agriculture and related activities. Water resource vulnerability in the semi-arid regions of western India is increasing due to variation in rainfall as temperature rises (Fang *et al*., 2019) [6]. Increased dry spell events and abrupt changes in the monsoon lead to severe droughts (Ma *et al*., 2019) [13]. Seasonal water scarcity and high temperatures have serious repercussions on agriculture, its productivity and ultimately on food security of the country. Sustainability of agriculture field is mostly dependent on the availability of land resource in the region and its vulnerability (Fitton *et al*., 2019) [7]. Pressure on land resource is increasing with very rapid rate due to increasing population. Area under agriculture in many parts of the country is reducing day by day due to stiff competition of different stake holders (Pandey and Ranganathan, 2018) [16]. Water resources occupy a special place among other natural resources due to life survival for all living beings. Water is the most widely distributed substance on the Earth and plays a vital role in both the environment and human life. Water is essential for sustaining life and at the same time, it is an important component for almost all developmental plans (Scanlon *et al*., 2023) [19]. The more accurate information about water and land resource availability and consequences are required for its proper and judicious planning and management to improve per unit area economic returns.

Traditional methods for the assessment of these natural resources are very cumbersome, time consuming and not economical. Now a day's geographical information system is one of the recent proven technologies for site specific assessment and planning of water and land resources. This technology is coupled with many hydrological models to assess and simulation of land and water resources within the area of interest. Different hydrological models are available which works with GIS interface such as MODFLOW, HEC-HMS, HEC-GEOHMS, HEC-WMS, HEC-RAS, WEAP, AGNPS, HYDRUS, HATWAB, SWAT etc. Among these USDA, Agricultural Research Service and Texas Agriculture University which works with GIS interface SWAT model is more reliable and better utilized for basin scale study (Gassman *et al.,* 2014). This tool is universally adopted for different work such as water and land resource assessment, water and land resource planning, water quality analysis, crop planning, water budgeting and many more applications with proper calibration and validation (Aloui *et al*., 2023; Arnold *et al*., 2012) [2, 3].

Study area

Arjuna river originates in the Sahyadri ranges at an altitude of 1000 m above mean seal level, near the village of Barki in the Shahuwadi tehsil of Kolhapur District. It is the tributary of the Kodawali river, which flows westward and eventually meets the Arabian Sea. The confluence of the Arjuna River with the Kodawali river occurs at Rajapur in the Ratnagiri district of the Konkan region. The Konkan region spans between 15^0 37' N to 20^0 20' N latitude and 72^0 39' E to 74^0 13' E longitudes.

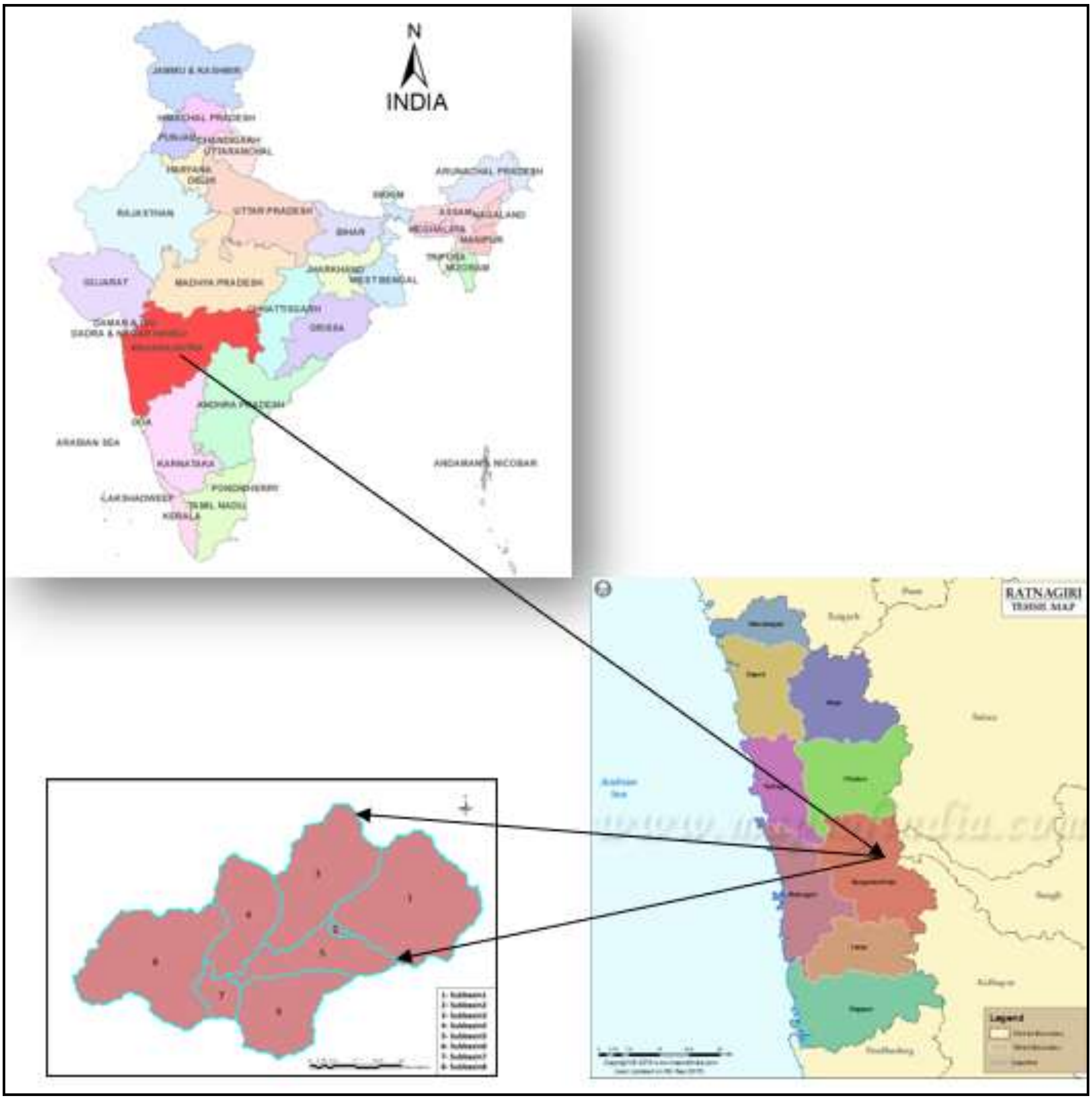

Fig 1: Location map of study area

Methodology

In present study, water balance study of Arjuna River basin was performed using ArcSWAT model. The database creation of SWAT model needs compatible raster/vector datasets (viz. shape files and feature data) and database files of SWAT's standard formats. The SWAT model requires four type of dataset, viz. Land Use Land Cover (LULC), Soil, topographical and hydro-meteorological data for evaluating the hydrological processes. In the present study data were procured from various sources.

Data Collection and model setup

The ArcSWAT model workflow comprises two major steps: ArcSWAT input data and ArcSWAT operation. A detailed workflow is illustrated in Figure 2.

ArcSWAT operation

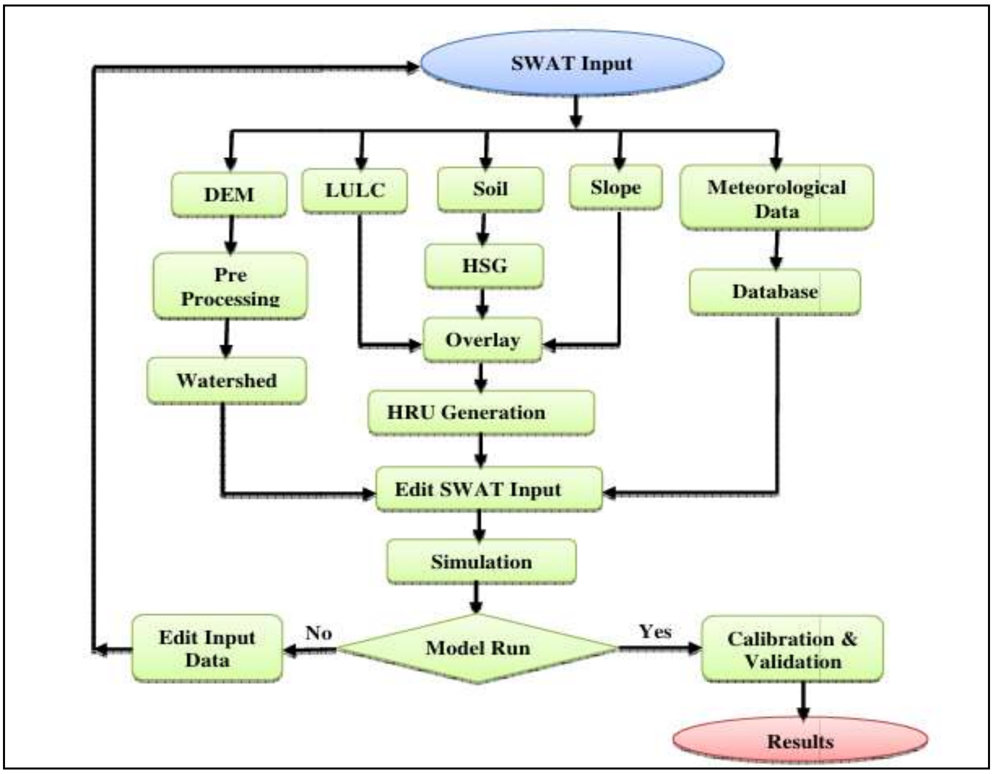

Fig 2: Flow chart of SWAT operations

ArcSWAT input data

Land use/ Land cover (LULC) data

The land use and land cover data (2012) for the Arjuna River Basin were obtained from the Regional Remote Sensing Service Centre, Nagpur, Maharashtra. The map was projected to WGS1984 UTM Zone 43N using raster projection in ArcMap 10.3 before being imported into ArcSWAT. The LULC map of Arjuna River basin is shown in Figure-3.

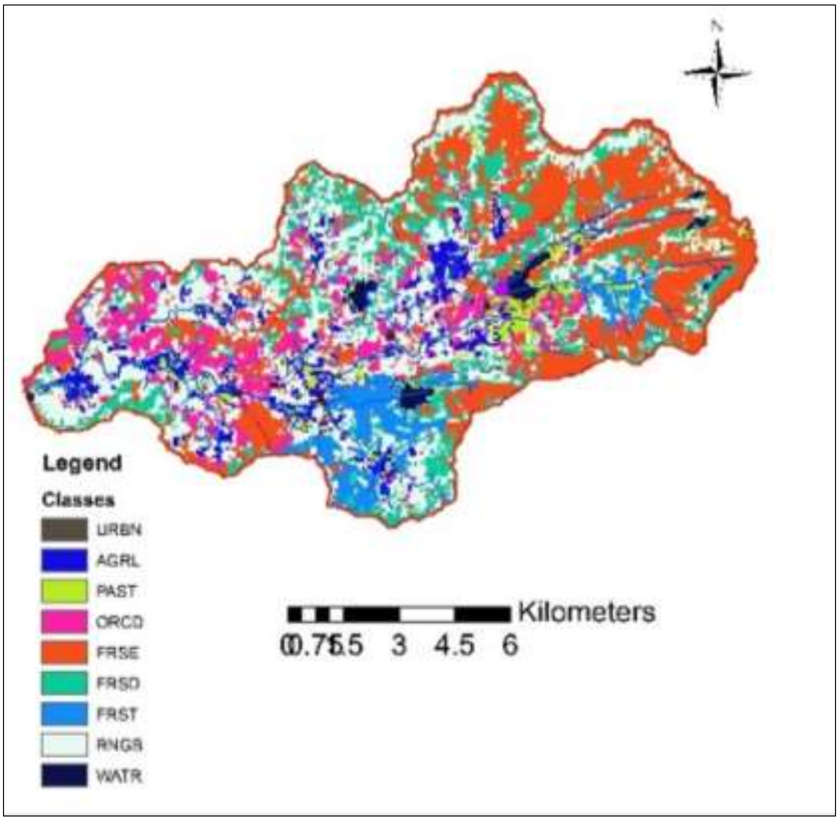

Fig 3: Land use/Land cover map of Arjuna River basin

Soil data

The soil data for the Arjuna River basin was obtained in the shapefile format at a scale of 1:50,000 from the Regional Remote Sensing Service Centre (RRSSC), Nagpur, Maharashtra. Subsequently, the soil map underwent projection to WGS1984 UTM Zone 43N using raster projection in ArcMap 10.3 before being imported into the ArcSWAT model. Additional hydrological attributes, such as porosity and saturated hydraulic capacity, were computed using the SPAW model. Layer-wise soil data for each soil type was then integrated into the ArcSWAT user soil databases. The Soil map of Arjuna River basin is shown in Figure-4.

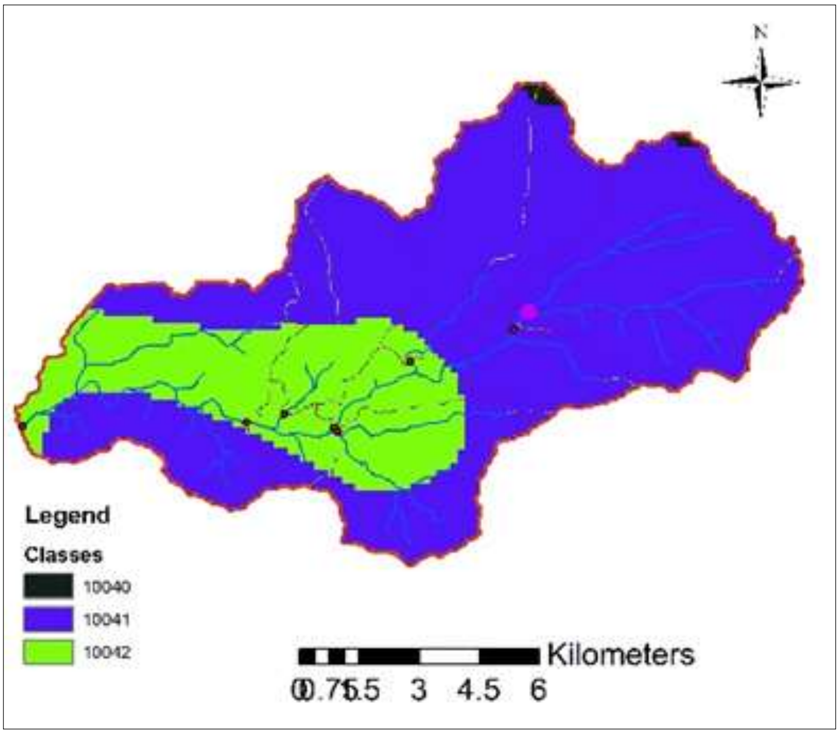

Fig 4: Soil map of Arjuna River basin

Meteorological data

For this study, a 31-year daily meteorological dataset (1985 to 2016) such as rainfall (mm), maximum and minimum temperature (^{0}C), maximum and minimum relative humidity (%), sunshine duration (hrs) and wind speed (km/hr) was obtained from the Karak station (Latitude: 16° 43' 7" N, Longitude: 73° 46' 13" E) within the Arjuna River basin. This data, sourced from the Water Resources Department, Hydrology Project, Nasik, Government of Maharashtra. In this study, 21 years meteorological data was used i.e from 1996 to 2016 for input of ArcSWAT model.

Water balance in basin

In this study, the ArcSWAT was utilized to simulate and analyze various components of the water balance within the Arjuna River basin. These components include evapotranspiration, surface runoff, baseflow and total precipitation. Each element plays a crucial role in understanding the hydrological dynamics and water availability in the area. Below is a detailed explanation of each component:

Total precipitation

The total precipitation is the sum of all forms of precipitation (rain, snow, sleet, etc.) that fall over a specified period. It serves as the primary input in the water balance equation and is critical for initiating the hydrological processes within the watershed. In the Arjuna River basin, precipitation predominantly occurs as rainfall, a characteristic feature of the region's climate.

Surface runoff

Arc SWAT calculates surface runoff using the Soil Conservation Service (SCS) Curve Number method, which takes into account land use, soil type, and antecedent moisture conditions.

Evapotranspiration (ET)

ArcSWAT estimates ET using several methods, including the Penman-Monteith equation, which considers factors like temperature, solar radiation, wind speed, and relative humidity.

Baseflow

Arc SWAT simulates baseflow using a recession constant that models the rate at which groundwater contributes to river flow, based on the physical properties of the watershed. Baseflow is a crucial component for the continuous support of aquatic ecosystems and for providing a stable water supply.

Integration of components into water balance

ArcSWAT calculates the water balance by using equation 1 as follows, (Neitsh *et al*., 2009).

$$SW_t = SW_0 + \sum(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where,

SW_t is the final soil water content, mm

SW_0 is the initial soil water content, mm

R_{day} is the precipitation, mm

Q_{surf} is the surface runoff, mm

E_a is the evapotranspiration, mm

W_{seep} is the water entering the vadose zone, mm

Q_{gw} is the return flow or baseflow, mm

At the HRU level, which is the smallest spatial unit in SWAT, the water balance equation includes additional components, such as groundwater flow from upland HRUs and lateral flow contributions (Terskii *et al*., 2019) [20].

Results and Discussion

Water balance of Arjuna River basin

The simulated mean annual water balance for the Arjuna River basin is presented in Figure 5, providing a comprehensive assessment of hydrological processes. The model simulates key fluxes, including actual evapotranspiration (ET), soil water content (SW), amount of water percolating out of root zone (PERC), surface runoff (SURQ), groundwater discharge in to reach (GWQ), lateral flow contribution to reach (LATQ) and net water yield to reach (WYLD). Analysis indicates an average annual precipitation of 1445.9 mm within the basin. Surface runoff emerges as the most significant component of the water balance (Figure 5).

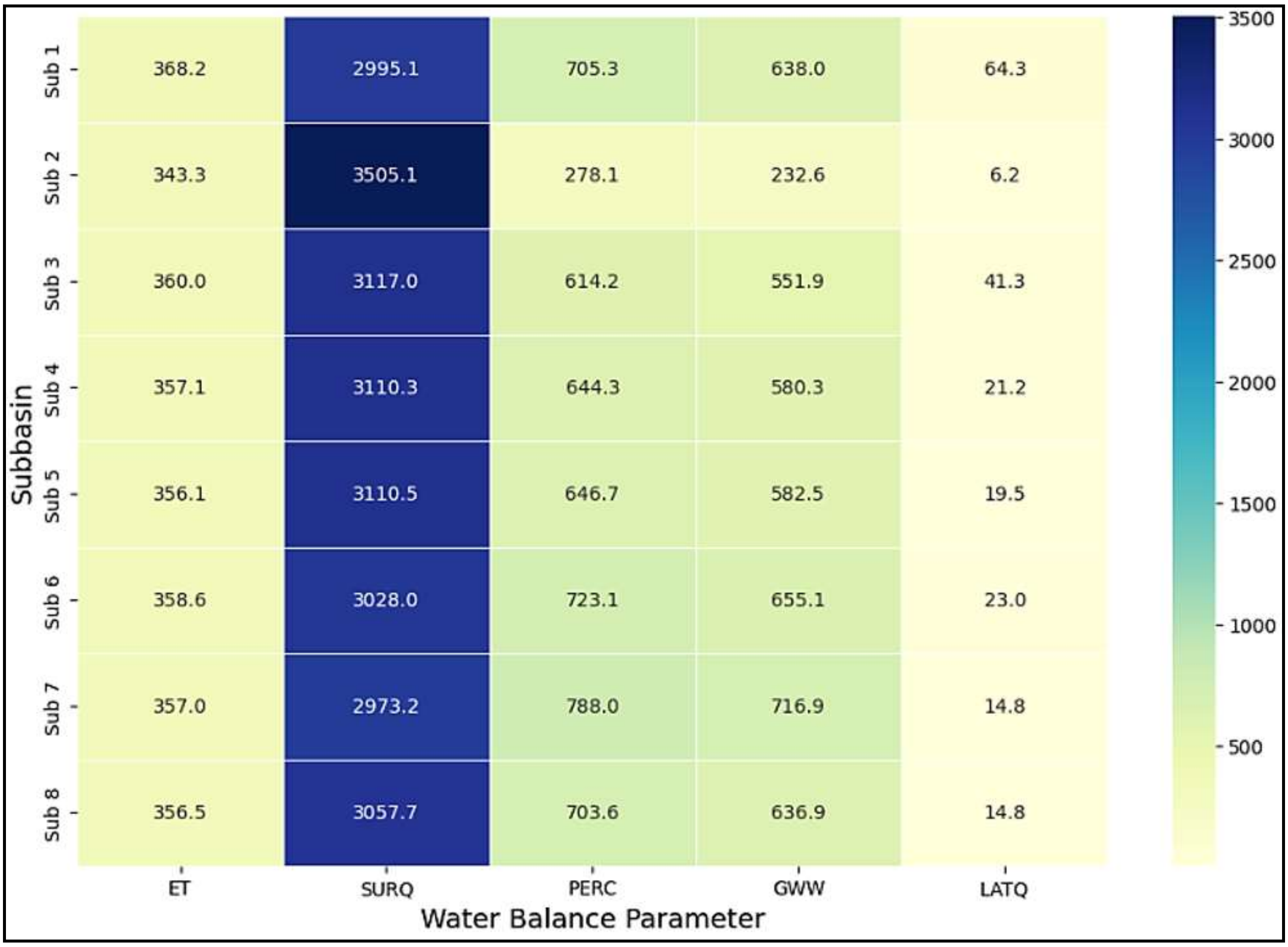

Fig 5: Simulated mean yearly water balance of the Arjuna River basin

Monthly water balance of Arjuna River basin

The water balance in the Arjuna River basin was simulated using equation 1. SWAT simulation outputs indicated high variability in monthly river flow (cubic meters per second), strongly influenced by the basin's weather and land use/land cover characteristics. Subbasin-wise monthly water resource availability was assessed for the period 1996-2016, with modeled water balance components presented in Table 1. Subbasin wise seasonal distribution of hydrological components of the Arjuna River basin are depicted in Figure 6 to 13. The results shows that total water lost due to the evapotranspiration is about 60-65% and remaining is distributed to discharge (surface runoff, lateral flow and return flow) and the percolation tank (the unsaturated zone, the shallow unconfined aquifer and the deep confined aquifer).

ET during December-May amounted to less than 10% of potential evapotranspiration (PET), highlighting severe moisture limitations for rabi and summer crops. The low ET during this time frame indicates a reduced capacity for crops to effectively transpire and utilize water, which can severely impact crop growth and yield. PERC comprised roughly 15% of rainfall from June-October, suggesting a significant contribution to groundwater recharge. Surface runoff (SURQ), also dependent on rainfall, was substantial from March to December and negligible during other months, underscores the challenge of efficiently capturing and storing monsoon rainfall for future utilization. GWQ peaked in September, becoming the primary source of river flow during post-monsoon periods, highlighting the critical role of groundwater in sustaining river ecosystems. Groundwater dynamics play a crucial role in maintaining river flows beyond the monsoon season, ensuring water availability for ecosystems and human activities. Subbasin1 showed the highest monthly LATQ, while Subbasin8 had the lowest, suggesting possible differences in soil permeability or topography.

The ArcSWAT model, calibrated from 1996 to 2003 and validated from 2007 to 2012, demonstrated robust performance, evidenced by satisfactory R^2 values (0.78 during calibration and 0.67 during validation) and Nash-Sutcliffe efficiency values (0.75 during calibration and 0.65 during validation).

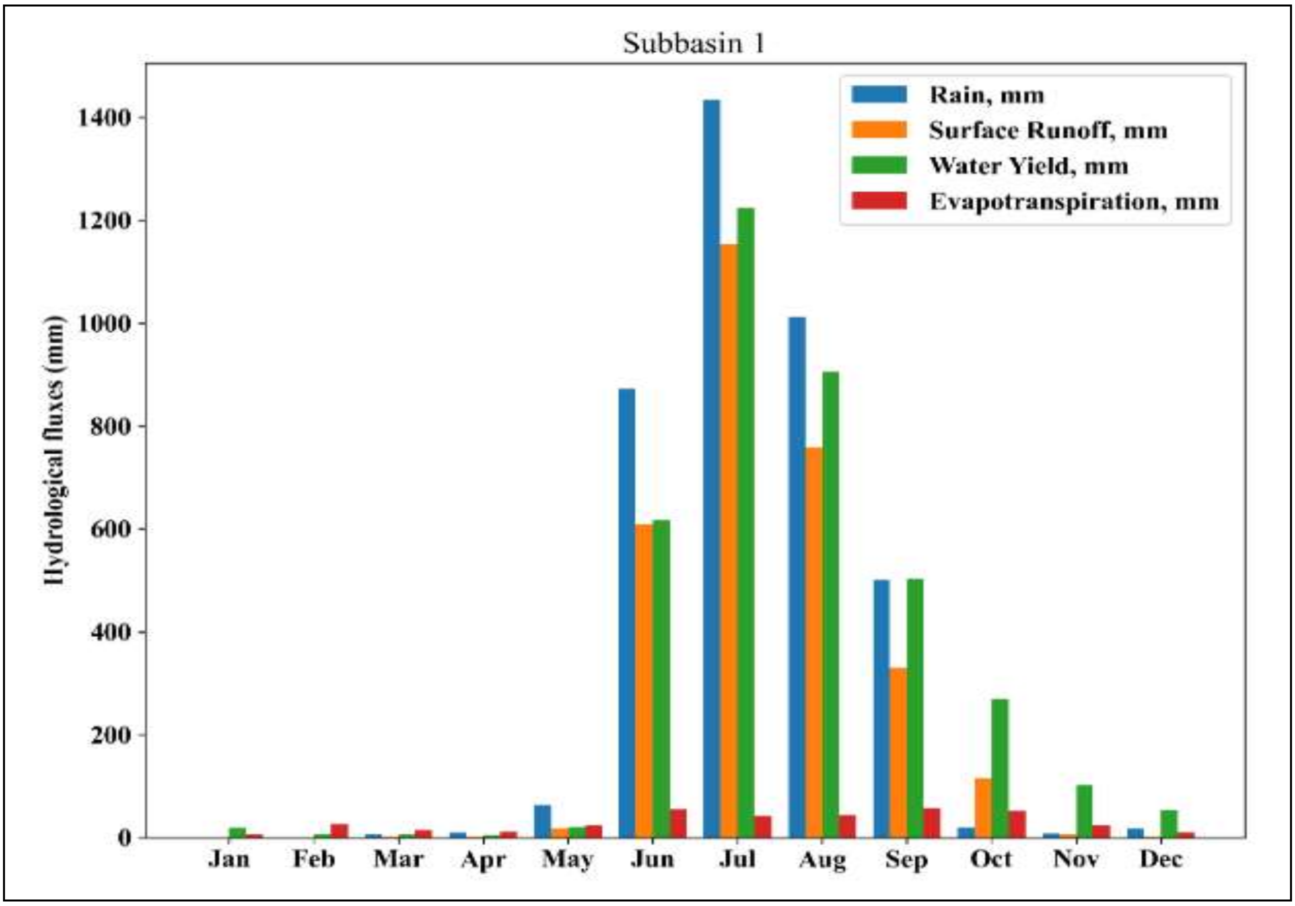

Fig 6: Seasonal distribution of hydrological components of Subbasin1

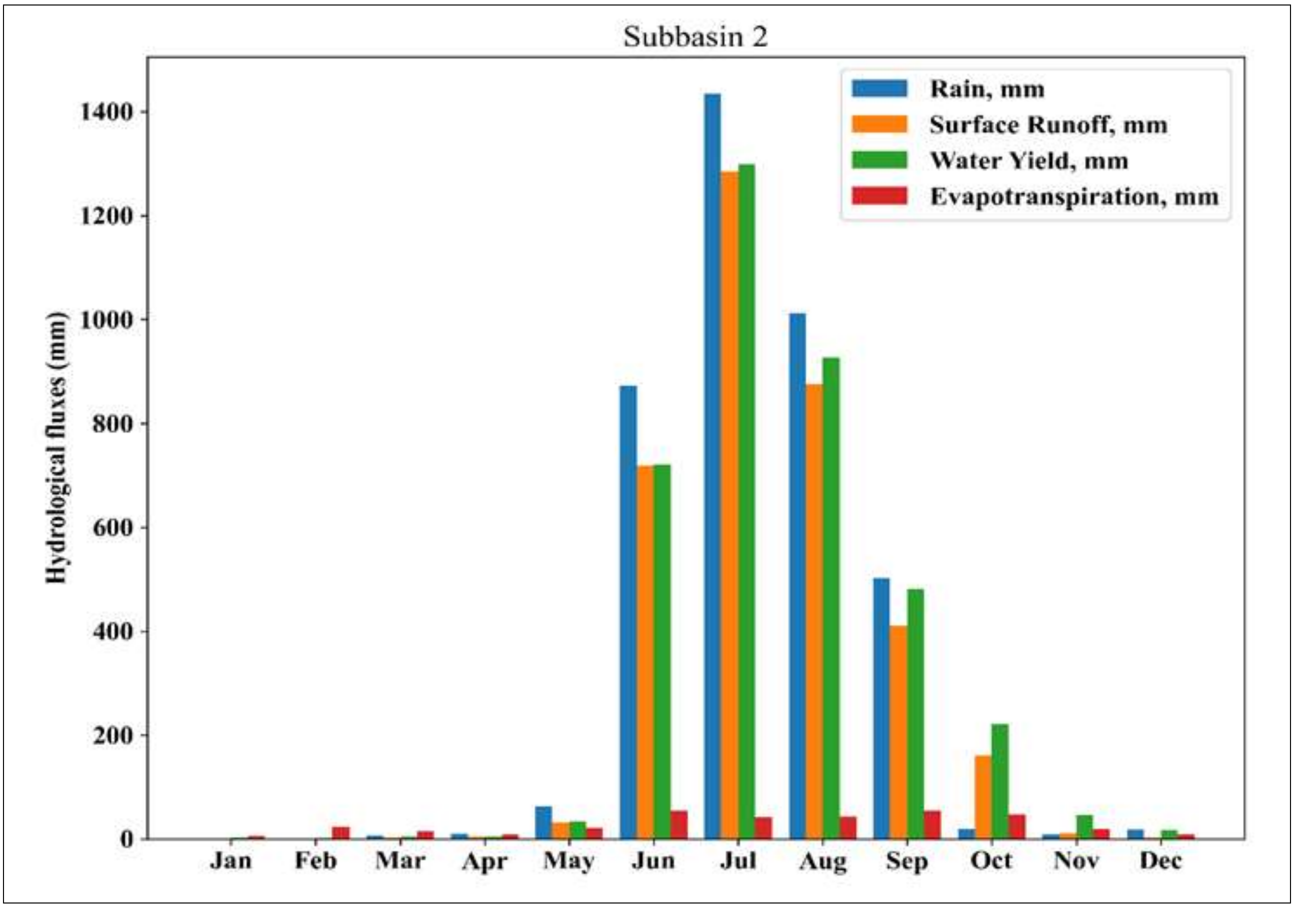

Fig 7: Seasonal distribution of hydrological components of Subbasin2

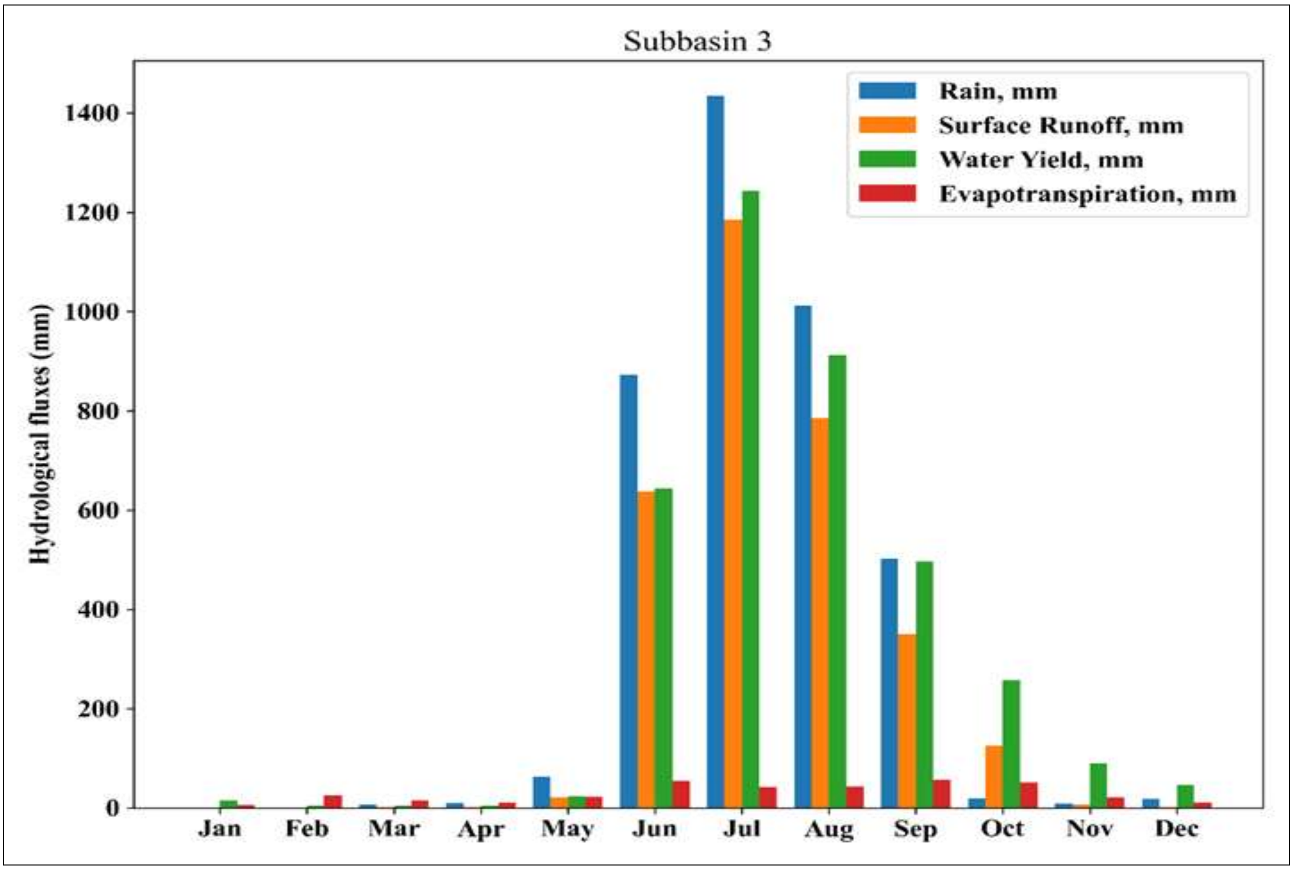

Fig 8: Seasonal distribution of hydrological components of Subbasin3

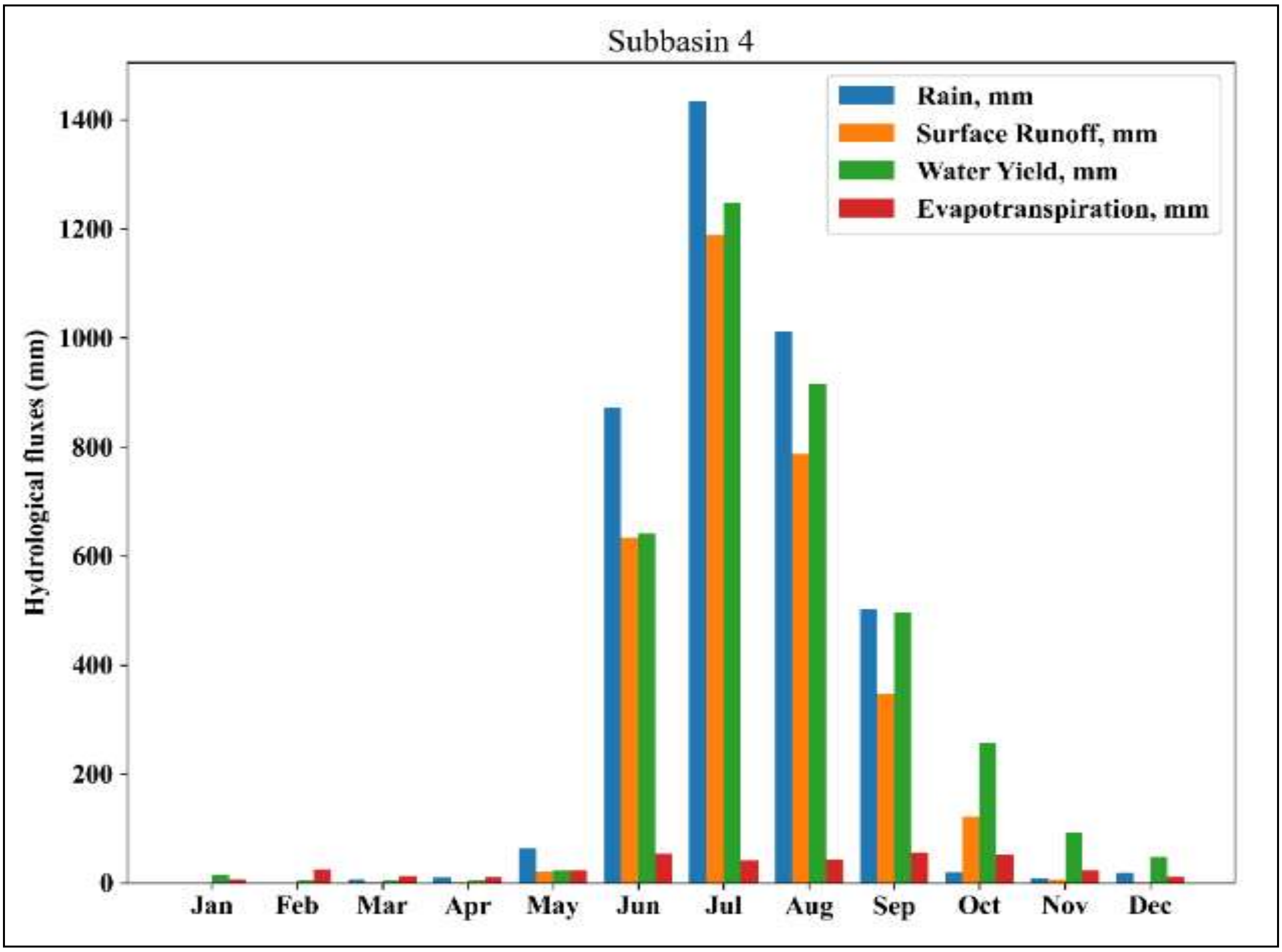

Fig 9: Seasonal distribution of hydrological components of Subbasin4

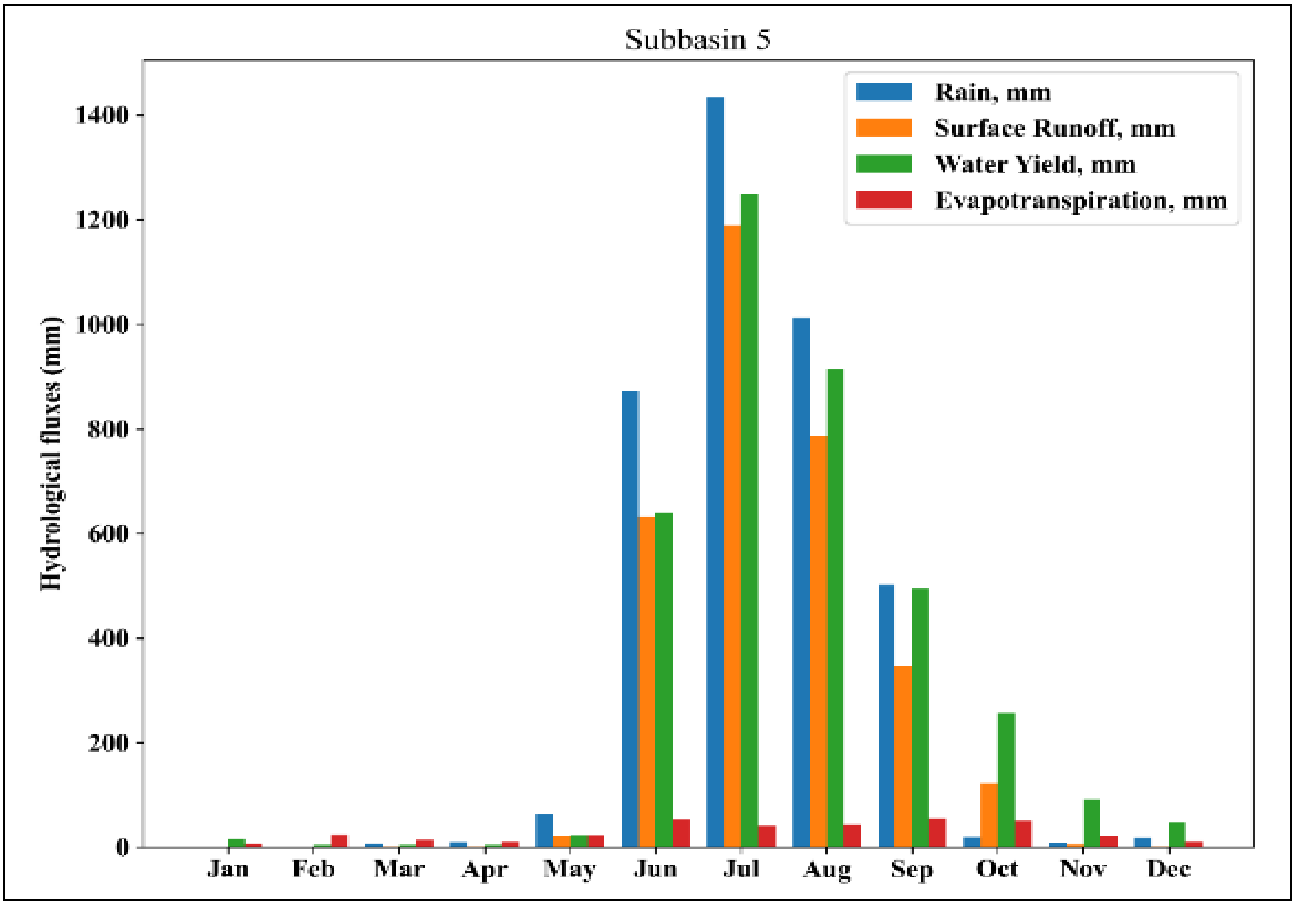

Fig 10: Seasonal distribution of hydrological components of Subbasin5

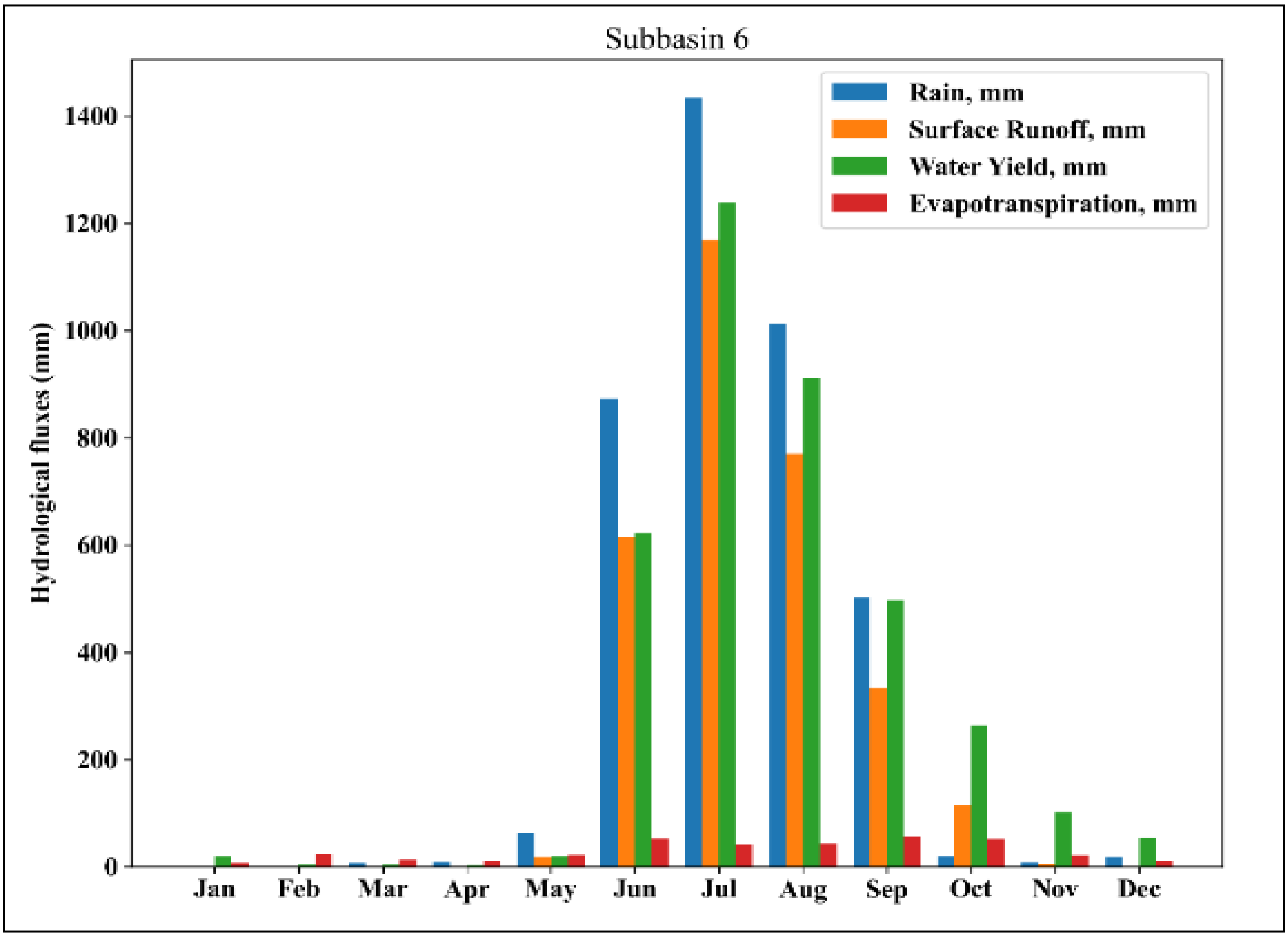

Fig 11: Seasonal distribution of hydrological components of Subbasin6

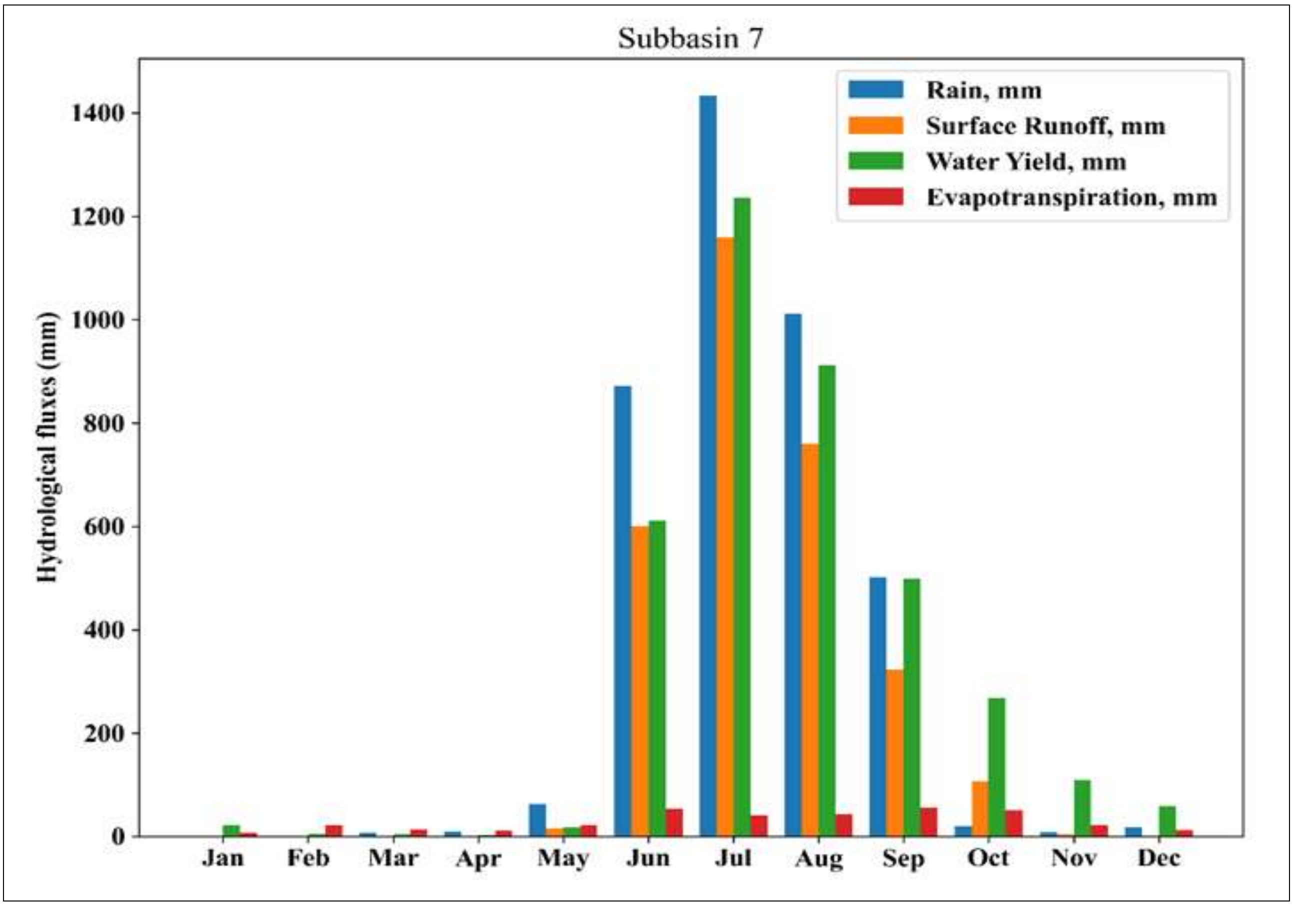

Fig 12: Seasonal distribution of hydrological components of Subbasin7

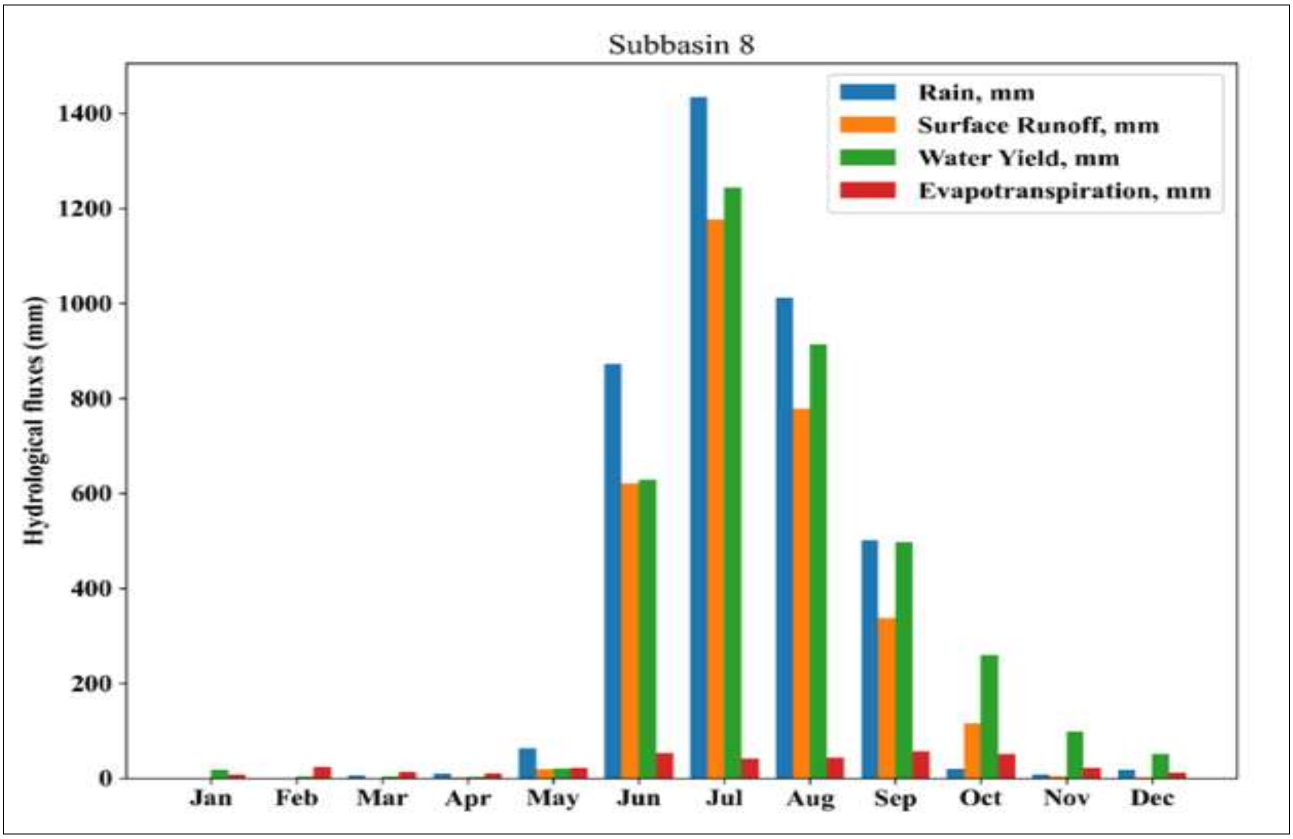

Fig 13: Seasonal distribution of hydrological components of Subbasin8

Table 1: Monthly water balance of Arjuna River basin

Parameters		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PRECIP mm		0.2	0.1	6.9	10.0	63.0	872.7	1433.7	1012.1	502.1	208.1	18.4	4.9
PET mm		155.2	163.6	199.6	195.7	192.9	91.7	45.6	49.4	85.7	121.3	138.1	153.6
ET, mm	Sub 1	6.3	26.9	14.9	11.5	23.5	55.6	42.7	42.9	57.1	52.7	22.9	11.2
	Sub 2	5.5	23.3	14.7	8.9	21.1	54.4	42.1	43.1	54.7	47.7	18.7	9.1
	Sub 3	6.2	25.6	15.3	10.8	22.4	54.0	42.0	42.9	56.5	51.5	22.0	10.8
	Sub 4	6.8	24.8	13.4	10.8	22.1	53.4	41.6	43.0	56.3	51.3	22.2	11.4
	Sub 5	6.8	24.0	13.9	10.7	22.1	53.8	41.9	42.9	56.0	50.8	21.9	11.3
	Sub 6	7.0	24.3	13.6	11.2	22.5	53.3	41.7	42.9	56.3	51.5	22.6	11.7
	Sub 7	7.6	22.4	13.2	11.3	22.4	53.5	41.7	42.8	55.9	51.0	22.8	12.4
	Sub 8	7.1	24.1	13.3	10.9	22.1	53.4	41.6	42.9	56.1	51.0	22.3	11.7
SW, mm	Sub 1	43.9	17.1	7.5	4.6	23.1	117.1	123.8	115.2	94.7	72.4	58.2	49.8
	Sub 2	41.0	17.7	6.5	3.5	12.4	86.8	101.4	96.1	81.4	66.2	53.7	46.3
	Sub 3	43.2	17.7	7.3	4.5	21.2	108.9	118.7	111.2	92.0	71.2	57.3	49.1
	Sub 4	40.5	15.8	7.4	4.7	22.6	111.7	119.6	111.9	92.3	70.3	55.7	46.8
	Sub 5	40.3	16.5	7.4	4.7	22.0	110.6	119.5	112.0	92.4	70.1	55.5	46.7
	Sub 6	40.3	16.1	7.7	4.9	23.9	115.8	123.5	115.5	94.9	71.0	56.0	46.9
	Sub 7	37.9	15.6	7.7	5.0	25.4	119.4	125.5	117.3	96.1	70.5	54.8	45.0
	Sub 8	39.5	15.6	7.4	4.7	23.4	113.7	122.1	114.4	94.1	70.4	55.3	46.2
PERC, mm	Sub 1	0.0	0.0	0.2	0.0	1.9	102.2	212.4	202.7	124.3	57.2	3.8	0.6
	Sub 2	0.0	0.0	0.0	0.0	0.2	22.6	91.0	97.6	50.8	15.3	0.5	0.1
	Sub 3	0.0	0.0	0.2	0.0	1.5	86.2	185.0	180.1	109.0	48.6	3.1	0.5
	Sub 4	0.0	0.0	0.3	0.2	2.2	92.3	189.6	183.7	115.5	55.3	4.5	0.7
	Sub 5	0.0	0.0	0.4	0.2	2.4	93.0	188.7	183.8	116.1	56.5	4.8	0.8
	Sub 6	0.0	0.0	0.4	0.3	2.8	107.7	208.9	201.5	129.7	65.2	5.7	0.9
	Sub 7	0.0	0.0	0.6	0.4	3.7	120.8	222.7	213.8	141.9	75.4	7.4	1.3
	Sub 8	0.0	0.0	0.4	0.3	2.8	104.4	202.2	196.1	126.7	64.0	5.8	0.9
SURQ, mm	Sub 1	0.0	0.0	1.3	1.3	18.0	608.8	1153.8	758.1	331.0	115.8	5.5	1.5
	Sub 2	0.1	0.0	3.4	4.1	32.6	719.0	1284.5	875.5	410.7	160.3	11.7	3.2
	Sub 3	0.0	0.0	1.8	2.0	21.6	636.8	1185.1	785.8	349.4	125.8	6.8	1.9
	Sub 4	0.0	0.0	1.6	1.7	20.4	633.7	1188.6	787.6	346.7	122.1	6.2	1.7
	Sub 5	0.0	0.0	1.7	1.8	20.7	633.0	1188.8	788.0	346.7	121.9	6.2	1.7
	Sub 6	0.0	0.0	1.3	1.3	18.3	615.1	1169.1	769.8	333.1	113.6	5.0	1.4
	Sub 7	0.0	0.0	1.0	0.9	16.2	600.8	1159.2	760.3	323.5	106.3	3.9	1.1
	Sub 8	0.0	0.0	1.4	1.4	18.9	620.9	1177.6	777.4	337.6	115.8	5.3	1.4
GWQ, mm	Sub 1	11.0	0.4	0.0	0.0	0.0	4.8	62.5	136.4	157.1	138.1	85.1	42.6
	Sub 2	1.5	0.0	0.0	0.0	0.0	0.5	13.0	49.3	67.4	57.7	32.2	11.0
	Sub 3	8.9	0.3	0.0	0.0	0.0	3.9	52.5	117.7	137.4	120.9	74.0	36.3
	Sub 4	10.7	0.7	0.0	0.1	0.1	4.8	55.5	121.8	141.7	126.3	79.1	39.5
	Sub 5	11.6	0.7	0.0	0.1	0.1	5.3	56.1	121.2	141.4	126.6	79.6	39.8
	Sub 6	13.7	0.9	0.0	0.1	0.1	6.2	65.1	136.0	156.7	140.9	89.5	45.9
	Sub 7	17.1	1.3	0.0	0.2	0.2	7.9	72.5	146.6	168.0	152.8	98.9	51.4
	Sub 8	13.6	0.9	0.0	0.2	0.1	6.2	62.9	131.6	152.1	137.2	87.4	44.7
LATQ, mm	Sub 1	4.5	3.2	2.7	2.1	1.7	2.7	6.0	8.9	9.7	9.5	7.4	5.9
	Sub 2	0.4	0.3	0.3	0.2	0.2	0.3	0.6	0.8	0.9	0.9	0.7	0.6
	Sub 3	2.9	2.1	1.8	1.4	1.2	1.8	3.8	5.6	6.2	6.0	4.7	3.8
	Sub 4	1.5	1.1	1.0	0.8	0.7	1.0	1.9	2.8	3.0	3.0	2.4	2.0
	Sub 5	1.4	1.0	0.9	0.7	0.6	0.9	1.8	2.6	2.8	2.8	2.2	1.8
	Sub 6	1.7	1.2	1.1	0.9	0.8	1.0	2.1	3.0	3.3	3.2	2.6	2.1
	Sub 7	1.1	0.8	0.7	0.6	0.5	0.7	1.3	1.9	2.1	2.0	1.7	1.4
	Sub 8	1.1	0.9	0.8	0.6	0.6	0.7	1.3	1.8	2.0	2.0	1.6	1.4
WYLD, mm	Sub 1	18.8	5.8	5.9	4.7	20.8	617.2	1224.0	906.8	502.6	268.8	103.0	54.2
	Sub 2	3.3	1.3	4.4	4.8	33.2	720.1	1298.5	926.9	481.0	221.1	46.5	16.4
	Sub 3	14.7	4.4	5.2	4.5	23.7	643.2	1242.9	912.1	497.2	257.5	89.9	45.7
	Sub 4	15.3	3.9	4.3	3.8	22.2	640.3	1247.6	915.3	495.6	256.3	92.2	47.1
	Sub 5	16.1	3.9	4.3	3.9	22.4	639.9	1248.3	914.9	495.2	256.3	92.6	47.2
	Sub 6	18.8	4.5	4.4	3.7	20.3	623.3	1238.0	912.2	497.8	263.3	102.2	53.7
	Sub 7	21.9	4.7	3.9	3.3	18.1	610.4	1235.1	912.6	498.6	267.1	110.0	58.6
	Sub 8	18.0	4.1	4.1	3.6	20.7	628.7	1243.5	914.1	496.4	260.4	99.2	51.7

Conclusions

SWAT model has capabilities of simulating surface runoff in small, medium and large watersheds. The ArcSWAT model effectively assessed water and land resources in the Arjuna River Basin, identifying critical hydrological patterns across eight subbasins. Evapotranspiration results in a water loss of 60 - 65% in the Arjuna River basin, with the rest distributed between surface runoff, lateral flow, return flow and percolation to unsaturated and aquifer zones. High surface runoff volumes across all subbasins, driven by intense monsoon rains and regional topography, frequently cause flooding. The ArcSWAT model, calibrated from 1996 to 2003 and validated from 2007 to

2012, demonstrated robust performance, evidenced by satisfactory R^2 values (0.78 during calibration and 0.67 during validation) and Nash-Sutcliffe efficiency values (0.75 during calibration and 0.65 during validation).

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