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Hydrological Simulation of Upper Betwa Basin under Climate Change Condition Using Geospatial Techniques

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ABSTRACT

A seasonal water budget analysis was carried out to quantify various components of the hydro-logical cycle using the Soil and Water Assessment Tool (SWAT). Degradation of water quality due to nonpoint-source (NPS) pollution is becoming a major concern for the society. Therefore, Best management practices (BMPs), widely accepted methods has been used for improving water quality which prevents the entry of pollutants into the water bodies. In the present work evaluation of agricultural best management practice of Upper Betwa basin using SWAT has been done. Continued research on agricultural water quality and assessment of environmental impacts of pollution are necessary to achieve the sustainable development of natural resources. In the monsoon season, an increasing trend in rainfall and a decreasing trend in ET were observed; this resulted in an increasing trend in groundwater storage and surface runoff. The winter season followed almost the same pattern. A decreasing trend was observed in summer season rainfall. The study evokes the need for conservation structures in the study area to reduce monsoon runoff and conserve it for basin requirements in water-scarce seasons.

Key Words: SWAT model, water management, hydrological model

I. INTRODUCTION

Water is at the core of sustainable development and its availability is influenced by many factors including socio-economic development, anthropogenic activities and climate variability. Therefore, the assessment of water resources availability under climate change impact and anthropogenic activities at regional and global scale have been intriguing issues to hydrologic research community in recent past (**Gosain et al., 2011; Pandey et al., 2019, 2017; Pingale et al., 2014**). As per Intergovernmental Panel Climate Change 5th assessment report (IPCC AR5), climate projections for the 21st century indicate that rising temperature and changing precipitation regimes are likely to affect the hydrological cycle and water resources availability (**Pachauri et al., 2014**). The adverse consequences of climate change may alter the spatiotemporal pattern of precipitation (frequency, intensity and duration) and increase the regional temperature and evapotranspiration. Moreover, changes in LULC due to increasing rate of population, deforestation and urbanization affect the sensitivity of the catchment and putting an additional stress on water availability, such as deficit in soil moisture, and depletion in groundwater level (**Trang et al., 2017**).

Water used for irrigation can be pumped from groundwater reserves or abstracted from stored surface water bodies. Crops also obtain water from precipitation. Competition for water resources is expected to increase in the future with certain pressure on agriculture, in order to meet the increasing demands of the expanding population. Therefore, water resource management is becoming an important issue from past decades such as development of water bodies for future, protection of available water bodies from pollution and over exploitation in order to prevent disputes. India is facing a major challenge in the management of freshwater in terms of rapidly rising population and increasing agricultural, industrial and other requirements. Sustainable management of water

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resources has become a major issue. The inefficient usage of water for irrigation, environmental impacts such as groundwater depletion and contamination adds to the problem. A basin or its sub-basin is hydrologically a self-contained area and a natural unit for water resources planning (**National Water Policy, 2012**). Basin level studies on climatic trends of this region is limited (**Mirza et al., 1998; Ranade et al., 2008**; **Mishra et al., 2009; Suryavanshi et. al., 2014; Mishra et al., 2017**).

LOCATION OF UPPER BETWA BASIN

The Upper Betwa river basin area (area=7770.85 km^2), location (77°10'E–78°10'E; 22°54'–24°50'N) is the study area. It is an historically important region located in the central part of India (Figure no. 1). The betwa river an interstate river between the two states MP and UP. The river originates from Raisen District in Madhya Pradesh, travels through the industrial belt of Mandideep and Bhojpur, enters the neighboring state Uttar Pradesh at Hamirpur before joining Yamuna River. The total length of the river from its origin to its confluence with the Yamuna river is 590 km, out of which 232 km falls in MP and the rest 358 km in UP. The elevation of the Betwa river ranges from 106 m to 706 m above the mean sea level (m.s.l.) and it joins the Yamuna near Hamirpur in UP at an elevation of about 106 m. The basin is saucer shaped with sand stone hills around its periphery and clays underlain by Deccan trap basalts. During its course from the source up to the confluence with the Yamuna, the river is joined by a number of tributaries and sub-tributaries; some of the important rivers among them are Bina, Jamini, Dhasan and Birma on the right bank and Kaliasote, Halali, Bah, Sagar, Narain and Kaithan on the left bank. The climate of the Betwa basin is moderate, the air being mostly dry except during the southwest monsoon.

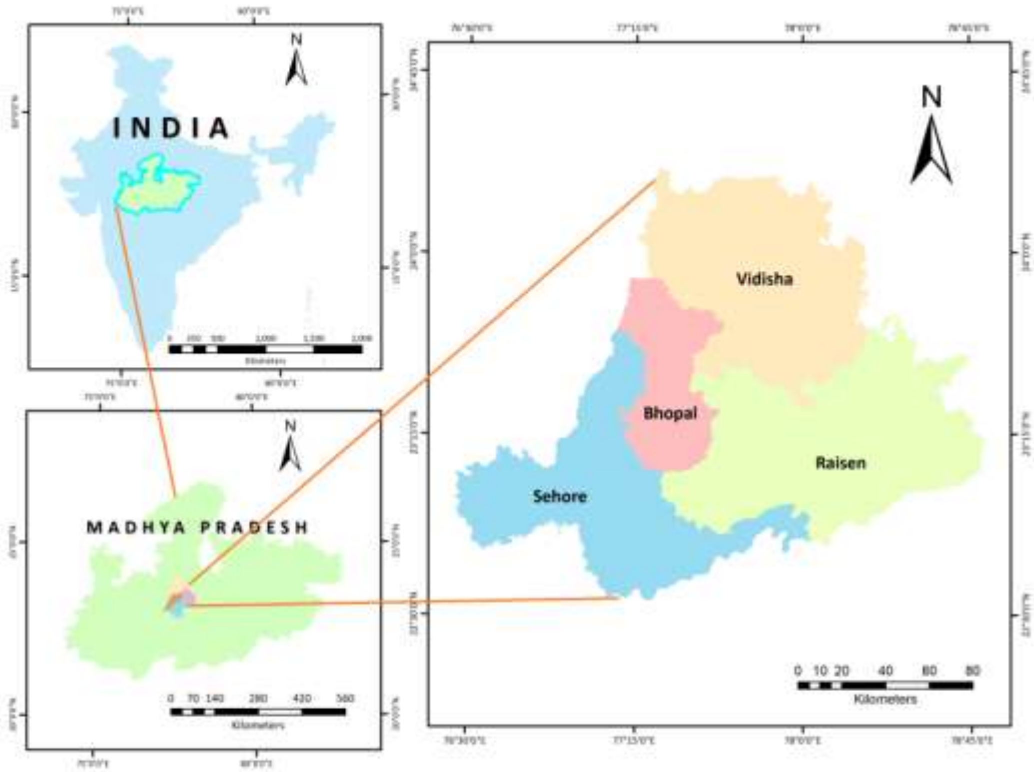

Figure no. 1. Field Experiment Location.

II. MATERIAL AND METHOD

PHYSIOGRAPHY OF UPPER BETWA BASIN

The study area is dominated by black cotton soil. Topography of the basin is undulating with the land slope varying from 0 to 67%. The basin comprises of 4 sub-basins. GIS based analysis of the drainage pattern was carried out and the drainage pattern was of 7th order as per Strahler's method (ESRI, 1994) of classification.

CLIMATE OF UPPER BETWA BASIN

The Climate of the Upper Betwa basin is moderate, the air being mostly dry except during monsoon season. The annual rainfall of the basin varies from 892 mm to 1261 mm with an average annual rainfall of 1138 mm. The average annual evaporation losses and average annual runoff are 1830 mm and 13430 million cubic meters (MCM) respectively (Chaube, 1988). Daily mean temperature ranges from a minimum of 8.1^{0}C to a maximum of 42.3^{0}C. The daily mean relative humidity varies from a minimum of 18% (April and May) to a maximum of 90% (August).

MAJOR CROPS GROWN IN UPPER BETWA BASIN

The major crops grown in the Betwa basin are wheat, gram, paddy, oilseeds, pulses, sorghum, maize, vegetables and fodder. The Agricultural Informatics Division of National Informatics Centre, Ministry of Information and Communication Technology, Government of India (http://dacnet.nic.in) has suggested wheat, paddy, maize and sorghum as the most suitable crop rotation in this region. In the present study the management scenarios will be focused on these four crops only.

LAND USE OF THE UPPER BETWA BASIN

Land use refers to "man's activity and the various uses which are carried on land". Land cover refers to "natural vegetation, water bodies, rocks/soil, artificial cover and others resulting due to transformations". In the present study, the land use/cover map of the study area was generated using remote sensing data. Most common land use classification method, the supervised classification, was used in this study. Maximum Likelihood Classifier (MLC) module was used for classifying the land uses. The classification was carried out by the Ground Control Points (GCPs). These GCPs were taken with the help of hand held GPS during field visit of the river basin. Each pixel in the image data set was then categorised into the land use class it most closely resembles. The classified land use/cover classes were water body, wasteland/barren land, settlements, scrub land, forest land and agricultural land.

Meteorological Data

Long term daily data (2000-2015) for rainfall, minimum and maximum air temperature, solar radiation, relative humidity, and sunshine hour were procured from India Metrological Department (IMD), Pune.

Hydrological Data

Observed monthly discharge data of Basoda (January 2000- December 2015), was obtained from the State Data Centre, Bhopal, M.P.

Satellite Data

Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) data was used for generation of the Digital Elevation Model (DEM) of the Betwa basin (Figure3.5). ASTER elevation data which is available on public domain (http://gdem.ersdac.jspacesystems.or.jp) under joint operation of NASA and Japan's Ministry of Economy, Trade and Industry (METI), provides high-resolution images in 15 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light with resolution of 30m.

The cloud free digital LANDSAT (ETM) data which covers the study area was downloaded by Global Land Cover Facility site. Satellite data of autumn season for the year 2001 was used to generate the land use/cover map of the Upper Betwa basin. The satellite data were obtained in three electromagnetic spectral bands (band 1: 0.63-0.69 μm, band 2: 0.75-0.90 μm and band 3: 1.55-2.35 μm) with 30 m spatial resolution.

HARDWARE AND SOFTWARE USED

Workstation equipped with core i3 Processor, SWAT Version 2012, SWAT-CUP and ERDASIMAGINE version 9.3 image processing software, ArcGIS version 10.4, available at Centre for Geospatial technologies, SHUATS, Allahabad, India were used in the present study. These facilities were used for analysis of the DEM, preparation of land use/land cover, soil maps and for model simulation.

Table: 1 Software used in project

Software used	Version	Purpose
ArcSWAT	2012	Watershed delineation, HRU's generation
SWAT-CUP (SUFI-2)	5.1.6.2	Calibration, validation, sensitive analysis, uncertainty analysis
ArcGIS	10.4	Re-projection, Map generation
ERDAS Imagine	9.3	LULC Classification

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III. RESULTS AND DISCUSSION

Watershed Delineation

The delineation of the study area was done from the DEM of ASTER data sets as shown in figure no. 2 DEM based flow direction and accumulation process is chosen to generate streams and outlets. The minimum and maximum elevations for Betwa basin were found to be 333 meters and 663 meters respectively with the mean value of 456.40 meters. The area of the basin is found to be 7770.87 km^2 from the DEM based delineation.

Sub basin and HRU Definition

The current study area was divided into 4 sub basins (Figure no. 2) by selecting the respective outlet points which included the site of observed discharge data to assist the calibration and validation process of the model. Each sub basin boundaries marks the end of a reach and also the end point where the accumulation point for all flow data from upstream reaches. It is then fed into the downstream sub basin and reach. Once the flow lines were established, the model customs other physical layers in order to determine the HRUs. For HRU analysis land use, soil, slope information of the study area is required as the input. These unique hydrological response units were as well defined by the model. The first run of the model produced 442 HRUs. The sub basin wise distribution of HRUs and elevation details are presented in Table no. 2 The minimum elevation value (333 m) was found in sub basin 1 while maximum elevation value (663 m) was found in sub basin 2. To capture the diversity of land use, soil and slope across Upper Betwa basin, the number of HRUs/100 km^2 of area was calculated. It was found that sub basin 3 is more complex (7.7 HRUs/100 km^2) while the sub basin 1 was least complex (3.8 HRUs/100 km^2).

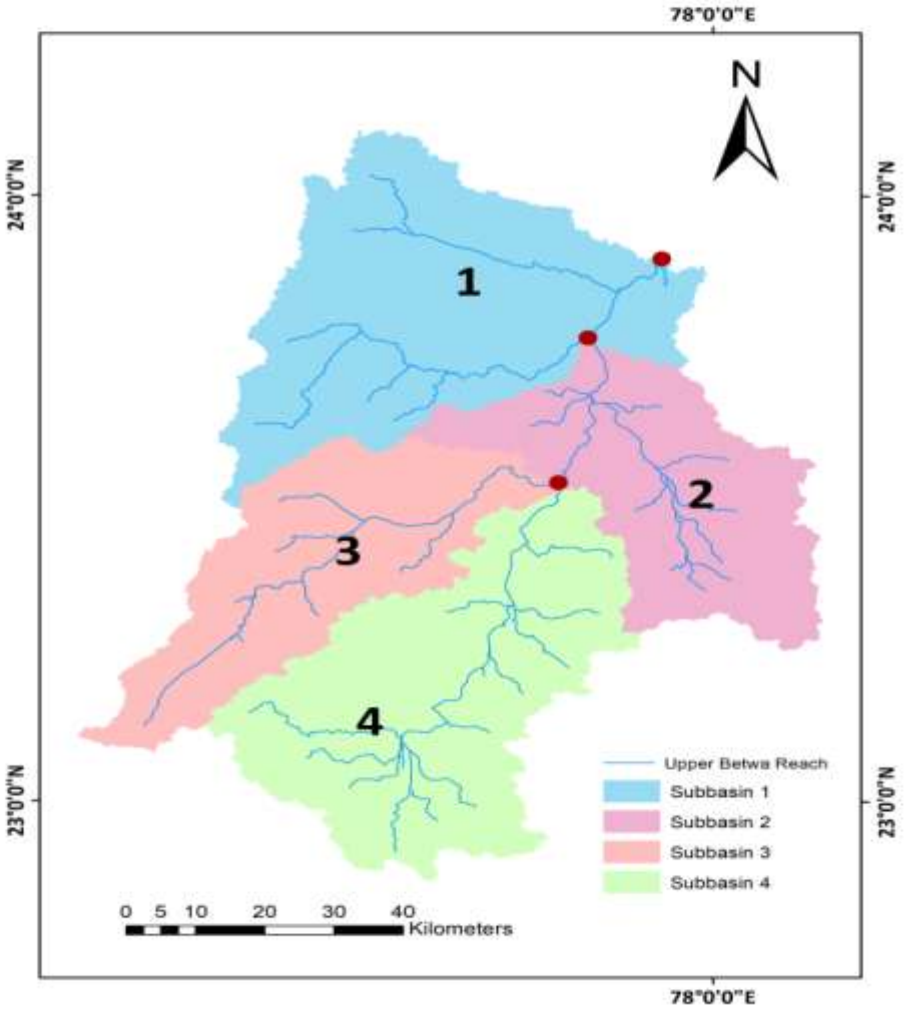

Figure no. 2 Delineated Sub-basins of the Upper Betwa basin

Table no. 2 Sub basin wise distribution of HRUs and elevation details

Sub basin No.	Number of HRUs	Area of sub basin (km^2)	Number of HRUs/ 100 km^2	Minimum elevation (m)	Maximum elevation (m)	Mean elevation (m)	Slope (m/km)
1	91	2370.89	3.8	333	569	445.92	4.69
2	111	1552.31	7.2	334	663	435.79	4.56
3	120	1551.85	7.7	378	644	480.07	4.79
4	120	2295.82	5.2	335	645	463.83	6.30
Whole Basin	442	7770.87	5.7	333	663	456.4	5.08

Model Calibration

Calibration is defined as the process of modification or adjustment of model parameters, within the mentioned ranges, to optimize the model output so that it ties with the observed data set. The calibration offers different parameters for adjustment through user intervention. These known parameters can be adjusted manually or automatically until the model output best matches with the observed data. This is done by using SWAT-CUP for calibrating outlet stream flow. The calibration was carried out on monthly basis with the observed monthly runoff for the years 2000 to 2015. The first four years of the modeling period (2000 to 2015) were kept for "model warm-up" in order to credibly set-up the states of its internal hydrological components e.g. groundwater store, soil moisture content etc. Parameters were modified and confirmed depending on nature of the parameter and its predefined ranges during the calibration.

Parameters used for Auto Calibration

Input variables used for auto calibration were soil conservation service (SCS) curve number, plant uptake compensation factor, soil evaporation compensation factor, base-flow alpha factor, groundwater delay time, effective hydraulic conductivity in main channel alluvium, Manning's "n" value for the main channel and surface runoff lag coefficient. The fitted value of these calibrated parameters are depicted in below Table no. 3.

Table no. 3 Parameters with their range and fitted range of values

Rank	Name	Description	Fitted value	Minimum value	Maximum value
1	CN	SCS runoff CN for moisture condition II	73.98	35	98
2	ALPHA_BF	Baseflow alpha factor (days)	0.071	0	1
3	GW_DELAY	Groundwater delay (days)	19.45	0	50
4	EPCO	Plant evaporation compensation factor	0.901	0	1
5	ESCO	Soil evaporation compensation factor	0.859	0	1
6	CH_K2	hydraulic conductivity in main channel (mm/hrs)	85.35	0.01	150
7	CH_N2	Manning coefficient for main channel	18.69	0.008	30
8	SURLAG	Surface runoff lag coefficient	7.80	0	10

SEASONAL WATER BALANCE ANALYSIS OF UB BASIN AT SUBBASIN LEVEL

For better understanding of the hydrological processes of UB Basin, a seasonal water balance analysis was performed at sub basin level. The water year (June-May) is divided into three seasons i.e. (a) Monsoon season (June-Sept), (b) Winter Season (Oct-Jan) and (c) Summer Season (Feb-May). In this study, Monsoon season, Winter Season and Summer Season is referred as Season 1, Season 2 and Season 3 respectively.

Water balance analysis of Sub basin 1

It can be observed from Figure no. 3 and Table no. 4 that during monsoon season, about 90% (914 mm) of annual rainfall (1005.87 mm) occurs. Of the total yearly runoff of 515.54 mm (which is 51.04% of precipitation), 483.86 mm (93% of total) occurs in the monsoon season. The ET contribution in the monsoon season was found to be 260.05 mm which is 77% of yearly ET. The groundwater contribution to runoff is 112.98 mm which is 88% of the yearly groundwater contribution.

Table no. 4 Average monthly water balance of subbasin1 of UB Basin

Months	Rainfall (mm)	Surface Discharge (mm)	ET (mm)	GW contribution to Discharge (mm)
Jan	10.13	2.74	7.01	1.42
Feb	10.57	2.76	9.59	1.72
Mar	3.47	0.60	11.49	0.64
Apr	6.48	1.89	2.14	1.02
May	16.70	5.55	7.00	3.16
Jun	133.06	55.59	39.16	13.31
Jul	304.65	168.71	80.74	33.13
Aug	346.70	205.04	85.69	41.16
Sep	130.39	70.27	54.42	25.35
Oct	25.14	10.95	22.08	5.72
Nov	11.96	4.94	10.26	1.33
Dec	6.59	2.23	7.68	1.58

In Season 2, the average rainfall obtained is only 53 mm. Of this rainfall, runoff is 20.87mm (38%), about 4% of the yearly runoff. The ET contribution in the winter season is found to be 45.05mm, which is 13% of the yearly ET. The groundwater contribution is 18.72%, which is only 7% of the yearly groundwater contribution to discharge.

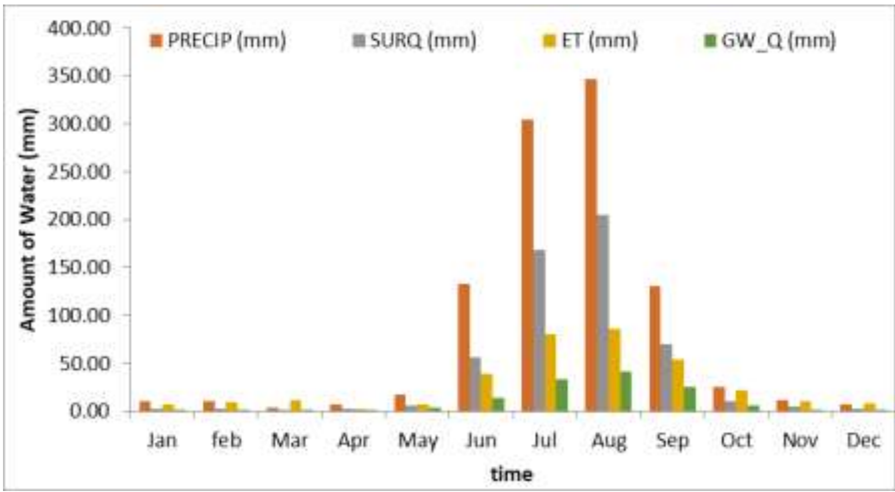

Figure no. 3 Average monthly water balance of subbasin1 of UB Basin

In season 3, only 37 mm of rainfall occurs between February and May as seen from the figure. About 10 mm of this rainfall is runoff. It is about 2% of the yearly runoff. The ET contribution in Season 3 is about 9% of yearly ET. However, the groundwater contribution is 4.42 mm, which is only 3% of the yearly groundwater contribution to discharge.

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Water balance analysis of Sub basin 2

From the Figure no. 4 and Table no. 5, it is observed that about 89% (1134 mm) of annual rainfall (1261 mm) occurs during Season 1. Of the total yearly runoff of 728.49 mm (which is 57% of precipitation), 681.72 mm (93% of total) occurs in the monsoon season. The ET contribution in the monsoon season was found to be 311.24 mm which is 70% of yearly ET. The groundwater contribution is 77.09 mm which is 90% of the yearly groundwater contribution.

In Season 2, the average rainfall obtained is only 90 mm. Of this rainfall, runoff is 38.5mm (42%), about 5% of the yearly runoff. The ET contribution in the winter season is found to be 79.49 mm, which is 18% of the yearly ET. The groundwater contribution is 7.56%, which is only 8% of the yearly groundwater contribution.

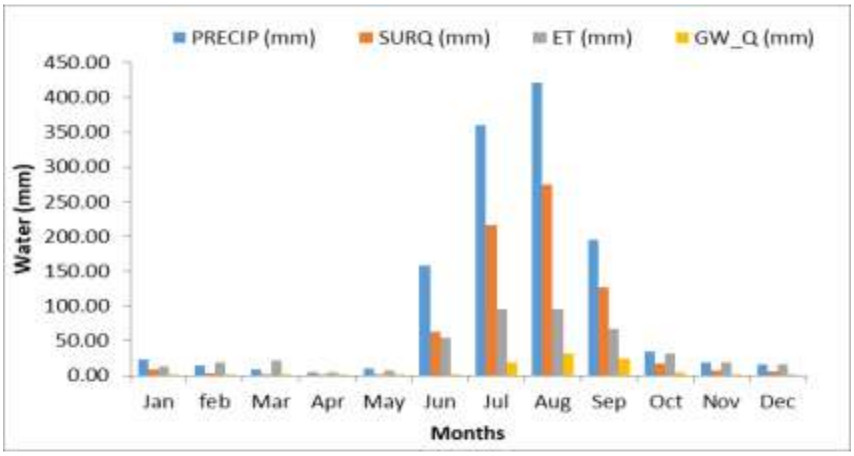

Figure no. 4 Average monthly water balance of sub basin 2 of UB Basin

In season 3, only 36 mm of rainfall occurs between February and May as seen from the figure 4 About 8 mm of this rainfall is runoff. It is about 1.2% of the yearly runoff. The ET contribution in Season 3 is about 11% of yearly ET. However, the groundwater percolation is only 0.95 mm, which is only 1% of the yearly groundwater contribution.

Table no. 5 Average monthly water balance of sub basin 2 of UB Basin

Months	Rainfall (mm)	Surface Discharge (mm)	ET (mm)	GW contribution to Discharge (mm)
Jan	22.27	9.10	12.64	0.68
Feb	13.80	3.47	18.16	0.77
Mar	8.05	1.74	21.40	0.09
Apr	5.04	1.05	4.27	0.03
May	9.84	2.01	6.87	0.06
Jun	158.61	63.28	53.56	2.16
Jul	360.13	216.50	95.38	18.90
Aug	420.91	275.07	95.80	31.66
Sep	194.72	126.87	66.50	24.37
Oct	33.62	16.80	32.03	4.59
Nov	19.01	6.79	18.34	0.68
Dec	15.81	5.81	16.48	0.91

Water balance analysis of Sub basin 3

As observed from the figure no. 5 and Table no. 6, about 90% (1058.41 mm) of annual rainfall (1175 mm) occurs during Season 1. Of the total yearly runoff of 663.6 mm (which is 56% of precipitation), 639.73 mm (96% of total) occurs in the monsoon season. The ET contribution in the monsoon season was found to be 260.5 mm which is 75% of yearly ET. The groundwater contribution is 107.94 mm which is 81% of the yearly groundwater contribution.

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Table no. 6 Average monthly water balance of sub basin 3 of UB Basin

Months	Rainfall (mm)	Surface Discharge (mm)	ET (mm)	GW contribution to Discharge (mm)
Jan	12.52	3.12	9.71	1.37
Feb	12.58	2.59	11.94	1.80
Mar	8.68	2.21	17.66	1.17
Apr	6.84	0.86	5.31	0.58
May	38.26	2.55	7.41	0.87
Jun	162.94	67.75	44.88	12.42
Jul	324.73	197.36	77.51	31.42
Aug	406.65	273.81	82.76	38.35
Sep	164.09	100.81	55.40	25.75
Oct	6.62	0.23	9.55	12.85
Nov	16.49	6.74	13.06	2.62
Dec	15.17	5.57	10.51	2.48

In Season 2, the average rainfall obtained is only 50 mm. Of this rainfall, runoff is 15.6 mm (30%), about 2% of the yearly runoff. The ET contribution in the winter season is found to be 42.83 mm, which is 12% of the yearly ET. The groundwater contribution is 38%, which is 14% of the yearly groundwater contribution.

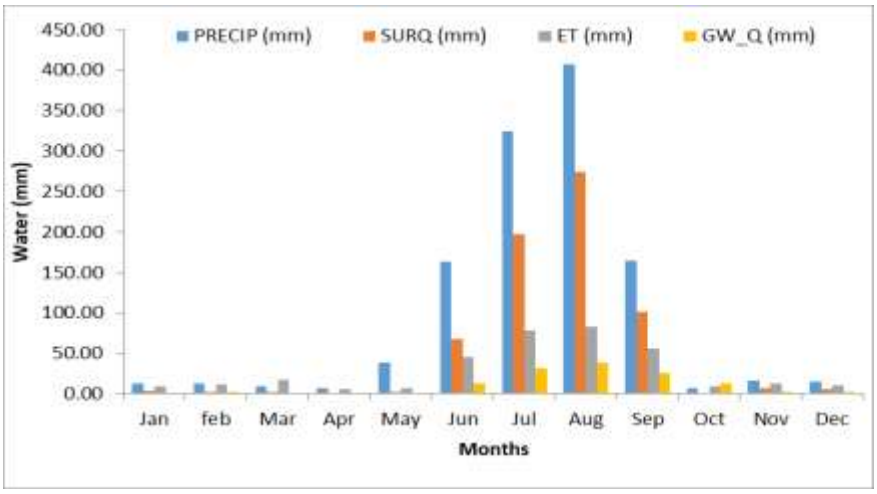

Figure no. 5 Average monthly water balance of sub basin 3 of UB Basin

In third season, 66 mm of rainfall occurs between February and May as seen from the figure. About 8 mm of this rainfall is runoff. It is about 1.23% of the yearly runoff. The ET contribution in Season 3 is about 12% of yearly ET. However, the groundwater percolation is 4.42 mm, which is only 3% of the yearly groundwater contribution.

Water balance analysis of Sub basin 4

As observed from the figure no. 6 and Table no. 7, about 90% (806 mm) of annual rainfall (892 mm) occurs during Season 1. of the total yearly runoff of 415.88 mm (which is 46% of precipitation), 390.18 mm (93% of total) occurs in the monsoon season. The ET contribution in the monsoon season was found to be 238.36 mm which is 76% of yearly ET. The groundwater contribution is 120.99 mm which is 90% of the yearly groundwater contribution.

Table no. 7 Average monthly water balance of sub basin 4 of UB Basin

Months	Rainfall (mm)	Surface Discharge (mm)	ET (mm)	GW contribution to Discharge (mm)
Jan	9.37	1.40	9.96	0.44
Feb	13.46	3.24	9.27	1.28
Mar	1.10	0.00	2.48	2.73
Apr	4.52	0.80	3.18	0.29
May	10.28	1.02	7.69	0.33
Jun	89.86	28.80	31.28	5.02
Jul	300.66	147.70	77.58	35.87
Aug	272.61	136.68	78.67	47.24
Sep	143.38	77.00	50.83	32.86
Oct	26.65	12.78	22.22	5.54
Nov	9.97	2.13	10.10	1.15
Dec	10.73	4.33	7.84	1.24

In Season 2, the average rainfall obtained is only 56 mm. Of this rainfall, runoff is 20.64 mm (36%), about 4% of the yearly runoff. The ET contribution in the winter season is found to be 50.12 mm, which is 16% of the yearly ET. The groundwater contribution is 14%, which is 6% of the yearly groundwater contribution.

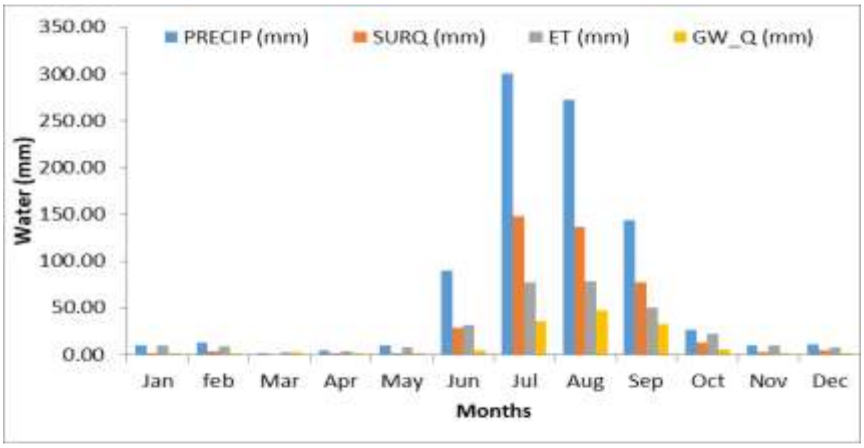

Figure no. 6 Average monthly water balance of sub basin 4 of UB Basin.

IV. CONCLUSION

The current study focused on the use of the SWAT model and the model has been calibrated and validated on the monthly data basis for the Upper Betwa river Basin. SWAT model set up was done using Arc SWAT interface. The interface assisted to create the stream network, delineation of the catchment boundary from the DEM and further subdivided the catchments into various sub-basins.

Due to unavailability of sediment data, only the impact of tillage and fertilizer treatments on the crop yield is discussed.

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