Assessment of Rainfall-Runoff Dynamics using ARC SWAT Modeling: A Comparative Analysis of Varying Sub-Basin Configurations

Kamuju.Narasayya
Scientist, Central Water and Power
Research Station Pune, India

Abstract:- Optimal management of natural water resources is a crucial strategy for mitigating the negative effects of climate extremes by ensuring sufficient water availability. A thorough assessment of hydrological system components is essential in watershed studies. In this context, the SWAT (Soil and Water Assessment Tool) model, integrated with ArcGIS, was applied to evaluate the overall hydrological conditions, with a focus on surface runoff in the 'KatePurna' catchment, a tributary of the 'Purna' River in the 'Tapi' Basin, India. KatePurna catchment has an area of 1130 square kilometers with a length of 108 km to meeting Point of Purna River. The data set for SWAT model running were Digital Elevation Model (DEM), slope map, soil map, LandUse LandCover (LULC) map, and climatic data in the form of precipitation, minimum/ maximum air temperature. The ArcSWAT model simulation performed for estimation of Rainfall-runoff in 2 scenarios, 1. by considering the sub-basins derived from default threshold value and 2. by increasing threshold value so as to decrease number of sub-basins. Scenario-1 derived 23 sub-basins and model simulation results obtained a runoff depth of 266.63 mm. The scenario-2 derived 11 sub-basins and resulted runoff depth was 268.43 mm. The variation of runoff depth between two scenarios less than 1%. The SWAT model simulation results, when examined, reveal an interesting pattern like catchments with fewer sub-basins exhibited a higher runoff depth of 268.43 mm, whereas those with a greater number of sub-basins displayed a lower runoff depth of 266.63 mm. The model could not be calibrated due to a lack of sufficient data required for the calibration process. Despite this, the SWAT model's results related to the water balance elements in the watershed demonstrate its effectiveness as a tool for hydrological assessments, particularly in situations where data is limited or unavailable for various reasons.

Keywords:- *Hydrology, Catchment, SWAT, Runoff, SCS-CN*

I. INTRODUCTION

The SWAT model operates at the basin scale, employing a continuous-time framework with daily time intervals. It assesses the impact of management interventions on water, sediment, and agricultural chemical yields within ungauged basins [1]. The key elements comprising the SWAT model include hydrology, weather patterns, erosion dynamics, land management practices, soil temperature variations, pesticide usage, nutrient dynamics, plant growth processes, channel characteristics, and reservoir routing mechanisms. However, only a limited number of studies have investigated the hydrological conditions of the specified region using the SWAT model

Among the plethora of watershed simulation and assessment models, the SWAT (Soil and Water Assessment Tool) stands out as a significant and impactful tool in this domain. Numerous researchers have conducted evaluations of the SWAT model across diverse conditions worldwide and at various watershed scales. The SWAT model has become one of the most widely used tools for basin studies and is frequently applied to address a range of hydrological and environmental challenges. [2].Surface runoff, a crucial element of the hydrological cycle, garners significant attention for both quantitative and qualitative assessment, as well as frequency analysis. Its prominence stems from being the most conspicuous and impactful influence on the surrounding environment among all components of the cycle. Some researchers have utilized different models and methods to calculate surface runoff. For instance, various approaches, including SCS, HEC-HMS, and HEC-1, were used to estimate runoff in the Nazanin catchments [3]. Also, Heedan et al.[4] employed GIS and NRCS to estimate the volume of runoff in the Koya Basin.

The use of Remote Sensing (RS) and Geographic Information Systems (GIS) in conjunction with the Soil and Water Assessment Tool (SWAT) model has become increasingly common for Rainfall-Runoff estimation [5]. Neitsch et al. stated that the Integration of Remote Sensing (RS) and Geographic Information Systems (GIS) data with SWAT modeling has improved the accuracy of Rainfall-Runoff estimation, particularly in ungauged or poorly gauged basins [6]. Remote sensing and geographic information systems (GIS) have been effectively utilized to

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

provide spatially distributed input data for SWAT modeling, facilitating improved Rainfall-Runoff estimation [7]. RS and GIS technologies have revolutionized the collection and integration of spatial data, enhancing the applicability of SWAT modeling for Rainfall-Runoff estimation in diverse hydrological settings [8]. The integration of RS and GIS techniques with SWAT modeling has facilitated detailed analysis of land cover, soil characteristics, and topography, leading to more accurate rainfall-runoff estimates at various spatial scales [9]. Application of the SWAT model for runoff simulation and sediment yield estimation in a Tropical catchment, "The study focused on a tropical catchment area for runoff simulation and sediment yield estimation." The research provides valuable insights for watershed management and conservation efforts in tropical catchments [10]. SWAT model was applied to simulate hydrological processes and sediment transport in the catchment. The research highlights the importance of sustainable land management practices to reduce soil erosion and sedimentation. The findings contribute to improved understanding of hydrological processes in the Upper Rwizi catchment [11]. Rong, W et al. "This study utilizes the SWAT model to simulate runoff and analyze the impact of climate change on a watershed, highlighting its suitability for assessing hydrological responses to changing environmental conditions [12]. The research presents the application of a coupled SWAT-MODFLOW model in the Odense Pilot River Basin, Denmark, showcasing its effectiveness in integrated watershed-groundwater modeling for runoff estimation and water resources management." The study presents a coupled watershed-groundwater model applied to the Odense Pilot River Basin, Denmark [13].

II. STUDY AREA

The KatePurna catchment area, encompassing parts of 'Akola' and 'Washim' districts in Maharashtra, is characterized by the flow of the KatePurna River. Originating from the Ajintha ranges near Kata village in Washim Tehsil, the river stretches approximately 108 kilometers. It drains a basin covering 1130 square kilometers before joining the Purna River, which traverses the central regions of Akola district. The KatePurna River flows through the tehsils of Mangrul, Akola, and Murtijapur, eventually merging with the Purna near Bhatori village. A significant feature within this catchment is the KatePurna Dam, an earthfill dam located at Mahan near Barshi Takali in Akola district. The dam creates the KatePurna reservoir, which spans 12.43 square kilometers. This reservoir is a crucial water source for the city of Akola and its suburbs, supplying water to over 8 lakh residents and 69 surrounding villages. The index map of study area as shown in Fig.1.

III. MATERIALS AND METHODOLOGY

A. Data Set

The digital data provided by accredited scientific sites is essential for fulfilling the requirements of certain scientific research projects, especially when the spatial conditions necessitate exclusive use of this data. Initially, the model starts by creating a work project, followed by a series of subsequent steps that utilize the following data.

- Digital Elevation Model (DEM): A 30-meter resolution DEM from the Shuttle Radar Topography Mission (SRTM) was utilized.
- Land Use-Land Cover map (LU-LC): GlobCover Land Use Land Cover map used
- Soil Map: Derived from the Digital Soil Map of the World (DSMW) version 3.6, provided by the Food and Agriculture Organization (FAO).
- Climate data: NASA-POWER web-portal used to down load point rainfall data covering within the KatePurna catchment at 3 locations namely Lait, Sahit and Mahan Dam site.

B. Methodology

Once the necessary data has been prepared appropriately for the model, including its extensions and geographical projections (with UTM selected in this case), work commences with the creation of a dedicated project. This project will encompass all inputs, outputs, measurement and analysis methods, and detailed reports. The SWAT sequence of operations is shown in Fig. 2.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

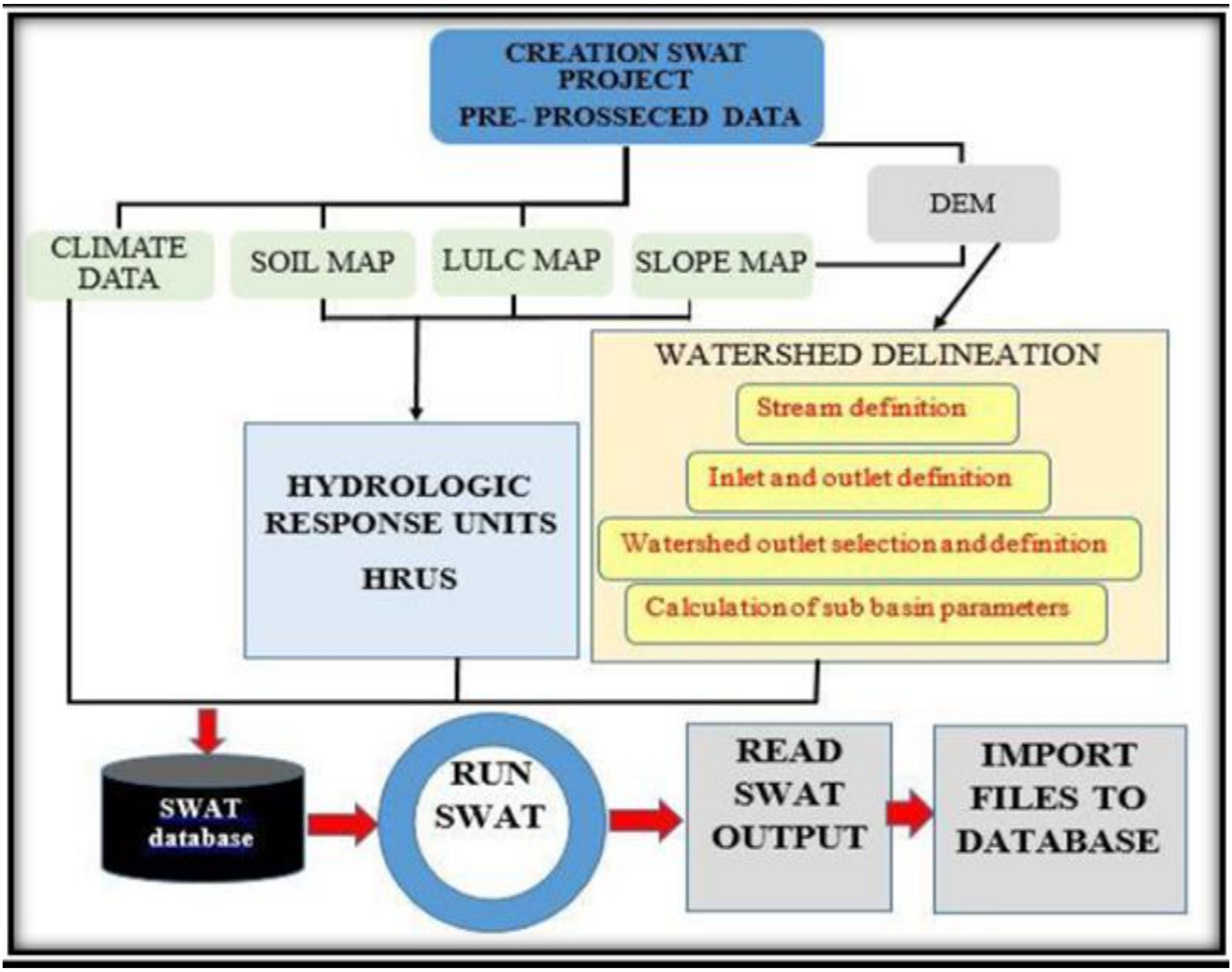

Fig 1: A Schematic Diagram of SWAT Model Methodology

According to Winchell et al. [14], SWAT enables users to set a sub-watershed threshold, which in this case was defined as 200 hectares (2 km²). Three outlets were manually placed on the main tributaries with the highest stream order, allowing the model to delineate the watershed and divide it into three sub-basins. Each sub-basin was further subdivided into smaller units known as Hydrological Response Units (HRUs).

Li, E. A et al. stated that HRU's are physically homogeneous non-contiguous areas assumed to respond similarly to inputs [15]. In the SWAT model, HRUs are formed by integrating three layers: a land use/land cover (LU/LC) map with 6 classes, a soil map with 2 soil types, and a slope map derived from the DEM. To improve computational efficiency and optimize the simulation performance of the SWAT model, thresholds must be set during the HRU creation process. [16].

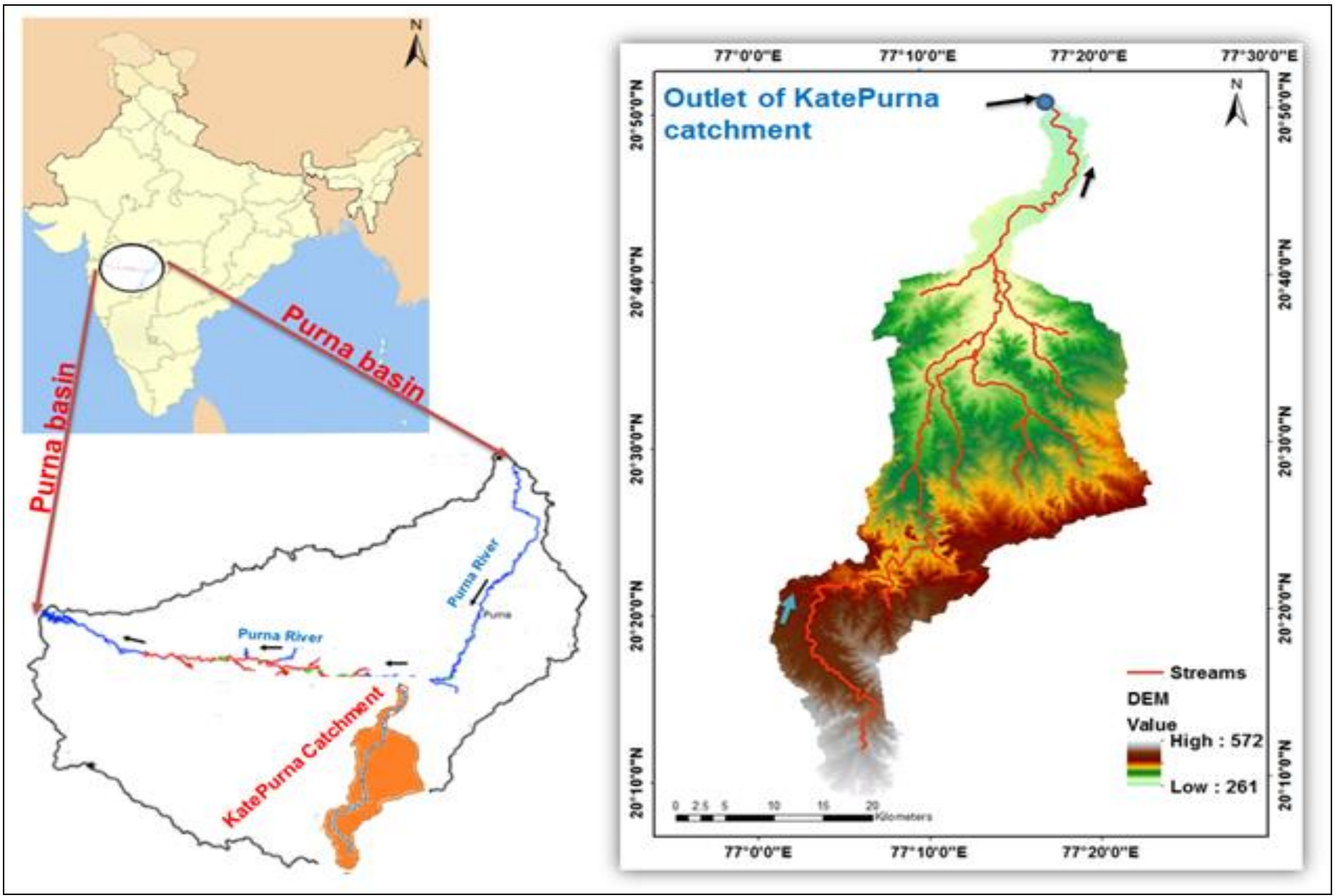

Fig 2: The SRTM DEM with a 30-Meter Resolution, Overlaid on a Hillshade, Highlights the Location of the Study Area

A threshold value of 10 was chosen for all three layers of LULC, soil and slope to ensure comprehensive representation of even the smallest parts. However, this approach led to the exclusion of some small areas in the watershed. Once the HRUs are defined, the weather data, which should already be entered into the model's database, are loaded. At the completion of this step, SWAT has successfully read and stored all the necessary data required to run the model.

A simulation period of thirty-four years, from 1990 to 2023, was chosen, with the first five years designated as warm-up years and thus excluded from the results. The SWAT model utilizes specific methods, including the SCS Curve Number (SCS-CN) method, to estimate surface runoff. This approach calculates the runoff volume and peak runoff rates for each Hydrologic Response Unit (HRU) using the SCS-CN equation.

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \text{ , } R_{day} > I_a \tag{1}$$

Where Q_{surf} is the daily runoff or rainfall excess in mm, R_{day} is the depth of daily rainfall in mm, S is the retention parameter (mm). I_a is the initial abstractions which are usually approximated as (0.2 S) usually, so the equation 1 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2\ S)^2}{(R_{day} - 0.8\ S)} \tag{2}$$

The retention parameter S equation is:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{3}$$

Where CN is the curve number.

According, Neitsch, et al., [17], SWAT depends on the water balance equation when simulating:

$$SW_t = SW_0 + \Sigma(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_{ti=1} \tag{4}$$

Where: SW_t is the final content of soil water content (mm); SW_o is the initial soil moisture content on a day *i* (mm); *t* is the time (days); R_t is the rainfall amount on a day *i* (mm); Q_t is the surface runoff on a day *i* (mm); ET_t is the Evapotranspiration on a day *i* (mm); P_t is the percolation on a day *i* (mm); QR_t is the volume of return flow on a day *i* (mm). Regarding estimating potential evapotranspiration. In this study the Evapotranspiration (ET) computation opted 'Hargreaves method', which requires precipitation and air temperature.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

IV. SWAT MODEL PROCESS

The initiation of the SWAT model process begins with delineating the watershed using spatial data, typically a Digital Elevation Model (DEM). From this, Hydrologic Response Units (HRUs) are derived, integrating soil data, land use/land cover data, and a slope map. Hydro-meteorological data, such as precipitation and temperature, are processed and organized into a database format, ready for utilization at the conclusion of the model's simulation process. The sequential flow of the SWAT model process is elaborated in the subsequent paragraphs.

A. Watershed Delineation

The main objective of this study is identify runoff with various number of sub-basins in the katePurna catchment. This could be possible by considering different threshold values while delineation of watershed. The delineation of watershed performed in 2 scenarios. The first scenario to derive watershed by considering default threshold value and second scenario is restrict threshold number to reduce the number of sub-basins by increasing threshold value. Initially, the default threshold value of 2084 ha and 2691 number of cells was used to derive 23 number of sub-basins of the catchment as shown in Fig.3. The second scenario of curtail or reduce sub-basins by increasing the threshold number as 5100 ha. with 6586 number of cells. Accordingly, the number of sub-basins are reduced as 11 as shown in Fig.4.

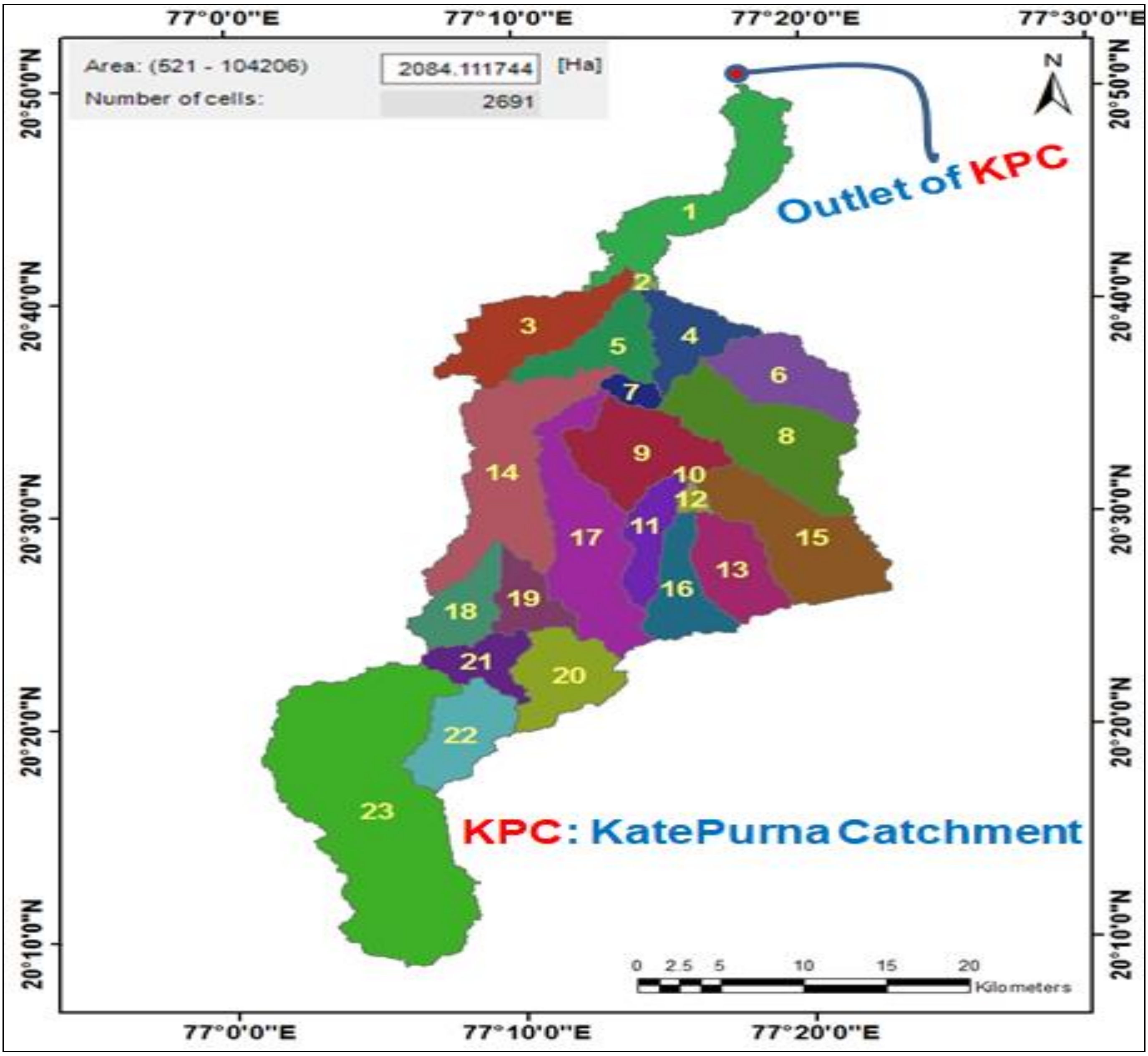

Fig 3: Default Threshold Value of 2084 ha.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

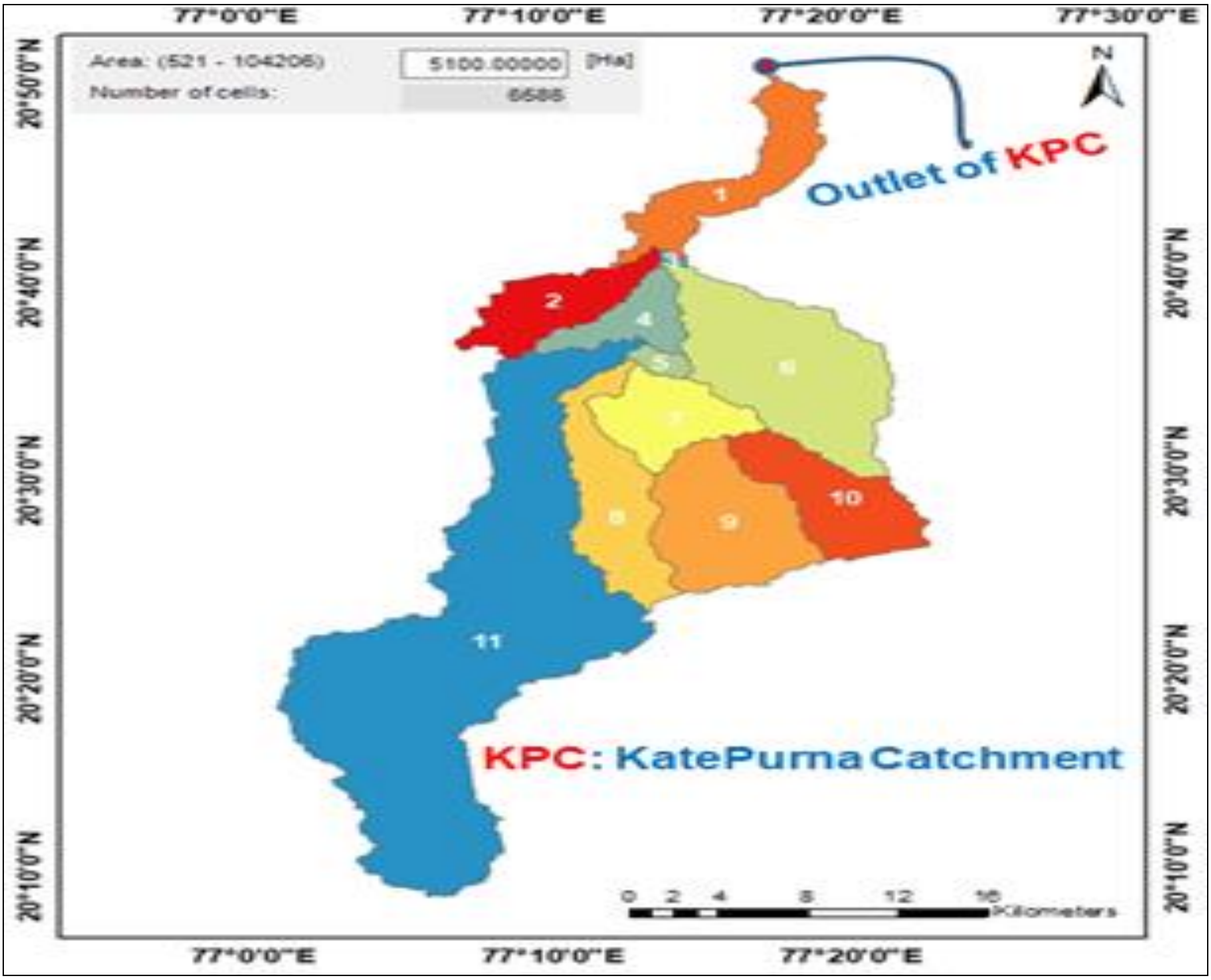

Fig 4: Threshold Value of 5000 ha.

In scenario-1, sub-basin no. 23 had the largest area at 414 km², while sub-basin no. 2 had the smallest area at 10 km², as illustrated in Figure 3. The analysis identified that there are six sub-basins with areas less than 100 km², and four sub-basins with areas ranging from 100 km² to 200 km².

According to Figure 4 of scenario-2, sub-basin no. 11 has the largest area at 324 km², while sub-basin no. 2 has the smallest area at 12 km². The remaining sub-basins have areas ranging between 100 km² and 200 km².

B. Hydrologic Response Units (HRUs)

The number of defined resulting HRUs were 129 units, distributed over the 23 sub-basins of first scenario under default threshold value. The number of HRUs were obtained 60 units, distributed over 11 sub-basins in second scenario under reduced threshold value. The significant variation in the distribution of HRU numbers across sub-basins is due to differences in land use/land cover (LULC) classes, slope, and soil types in both scenario-1 and scenario-2 sub-basins.

The results indicated that approximately 55% of the catchment area is classified as agricultural land, with the remaining area comprising pasture, grasslands, and water, as illustrated in Fig. 4. All soil classes belong to type D in terms of hydrological group, characterized by loam and clay-loam textures, as shown in Fig. 5. The potential for surface runoff is influenced by various factors such as soil type, land use patterns, and slope. Given that all the soils in the catchment are classified as type D, which has a high runoff potential, this combination results in elevated surface runoff values when simulated using the SWAT model.

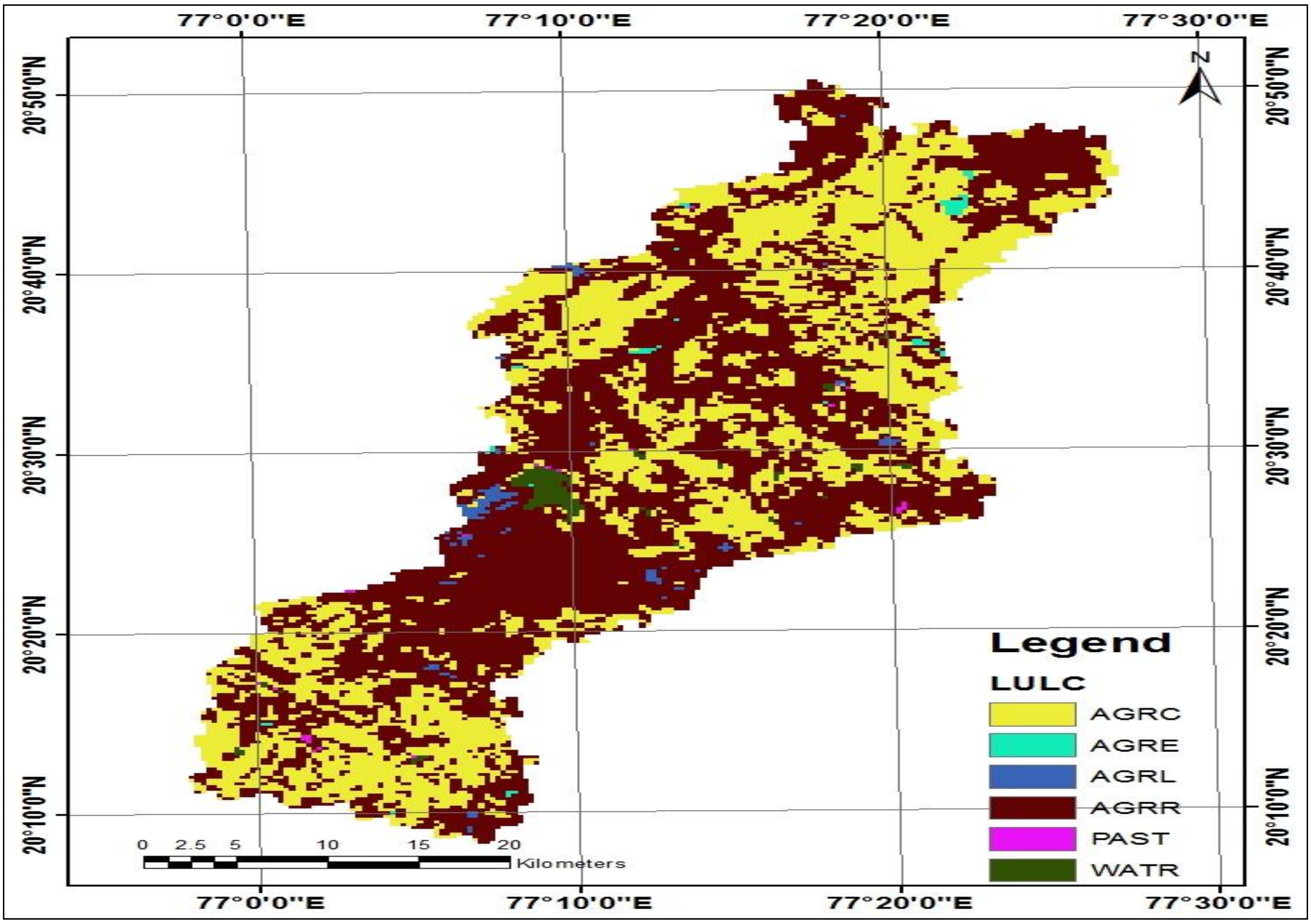

Fig 5: Land Use-Land Cover Classes

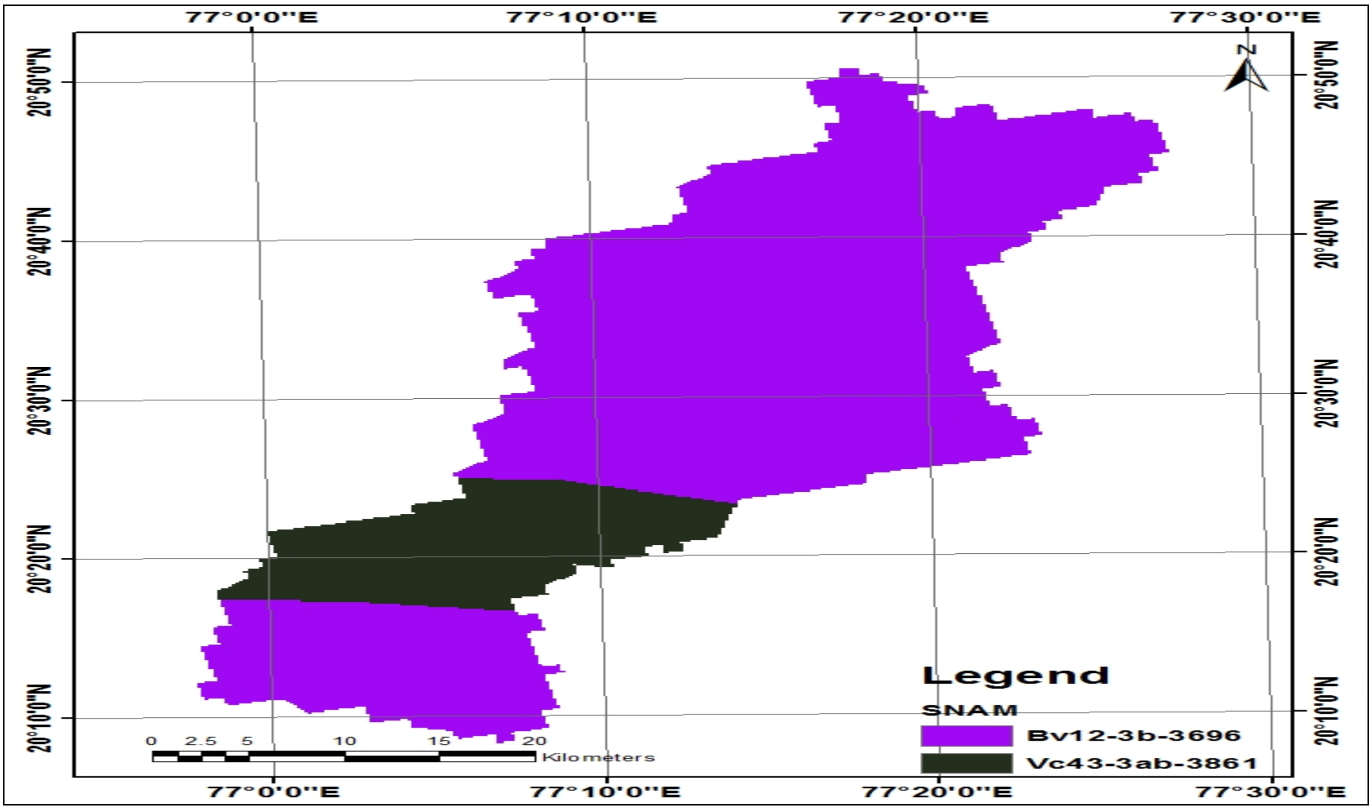

Fig 6: Soil Classes

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

V. RESULTS AND DISCUSSIONS

The SWAT model simulation performed in 2 scenarios of first one performed with 23 sub-basins under default threshold value and second scenario performed with reduced sub-basins of 10 numbers with increased threshold value. The results described with water balance, average monthly values of water balance components and annual average values of surface runoff and corresponding discharges.

A. Water Balance of KatePurna Catchment

The monthly averages water balance of KatePurna catchment (KPC) for the period from 1990-2023 is shown in Fig. 5 and Table (4). The water balance ratios of KPC under scenario-1 of 23 sub-basins were: stream flow 29.37% of precipitation, evapotranspiration (ET) 58% of precipitation, percolation 12.19% of precipitation, base flow 4% of the total flow, surface runoff 96% of total flow.

Under scenario-2 of 11- sub-basins, the results indicated that the annual average precipitation was 357.8 mm, with 95.66 mm contributing to the water yield of GBW, representing 26.7% of the total precipitation. The estimated runoff was 92.6 mm, accounting for 25.7% of the precipitation. Notably, approximately 74% of the rainfall is lost annually due to evapotranspiration. This highlights the significant influence of various factors on evapotranspiration and their substantial impact on the watershed's water balance.

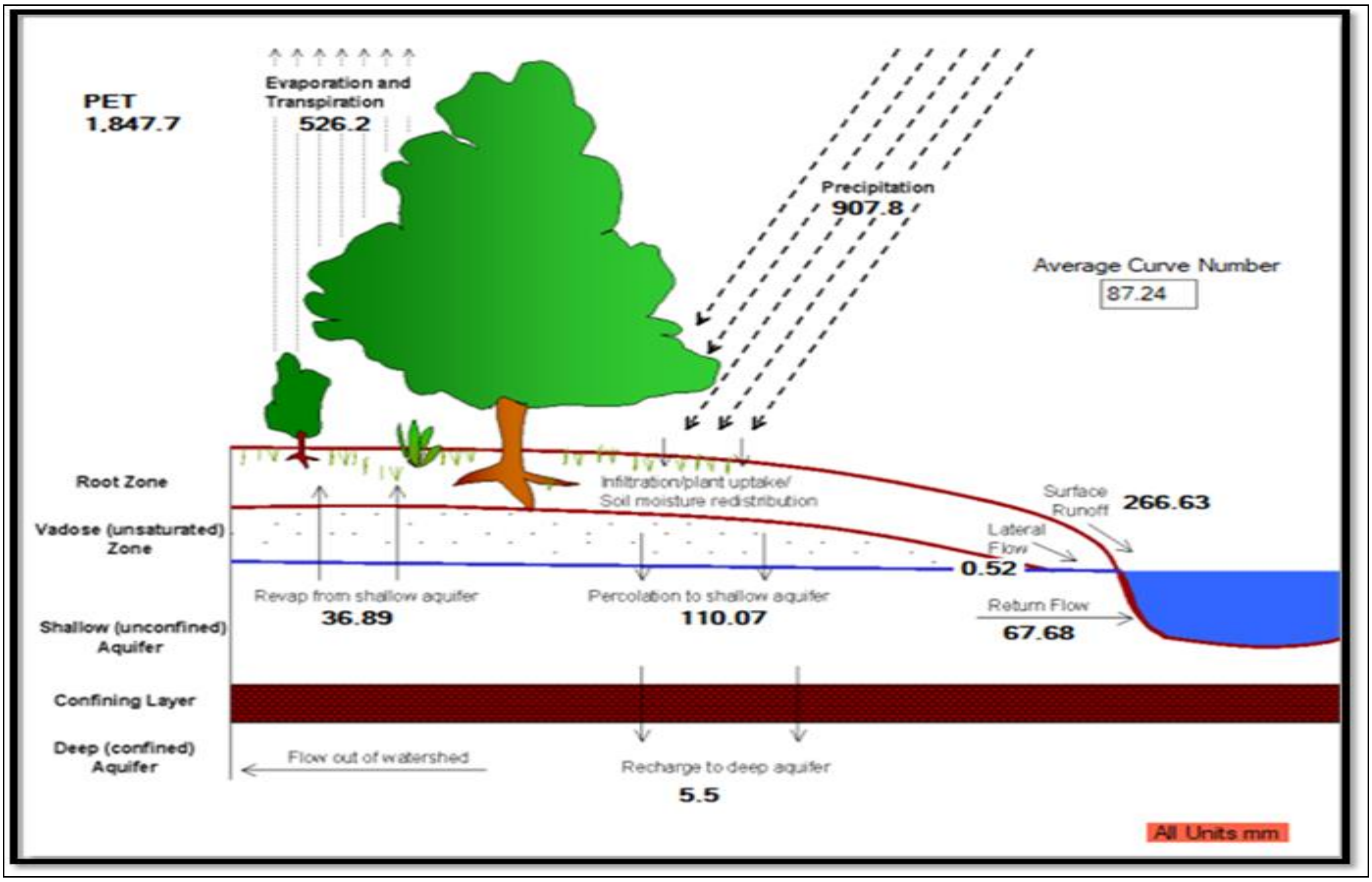

Fig 7: Water Balance Elements of the KPC Under Scenario-1 (A)

Usually, **more sub-basins** will likely predict higher and more accurate localized runoff, whereas **fewer sub-basins** might predict lower peak runoff values due to averaging effects and potentially less accurate total runoff. In this case, contrary to the usual expectation, watershed with a higher number of sub-basins delivers a lower amount of runoff compared to a watershed with fewer sub-basins. There could be several underlying reasons for this reversal of runoff as shown in figure 5 (A) and (B) also from Table 4.

- More detailed sub-basin division might reveal areas with higher infiltration rates that were not apparent in the coarser model, leading to lower runoff.
- Smaller sub-basins may identify more storage areas like depressions, small ponds that trap runoff, reducing the overall runoff.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

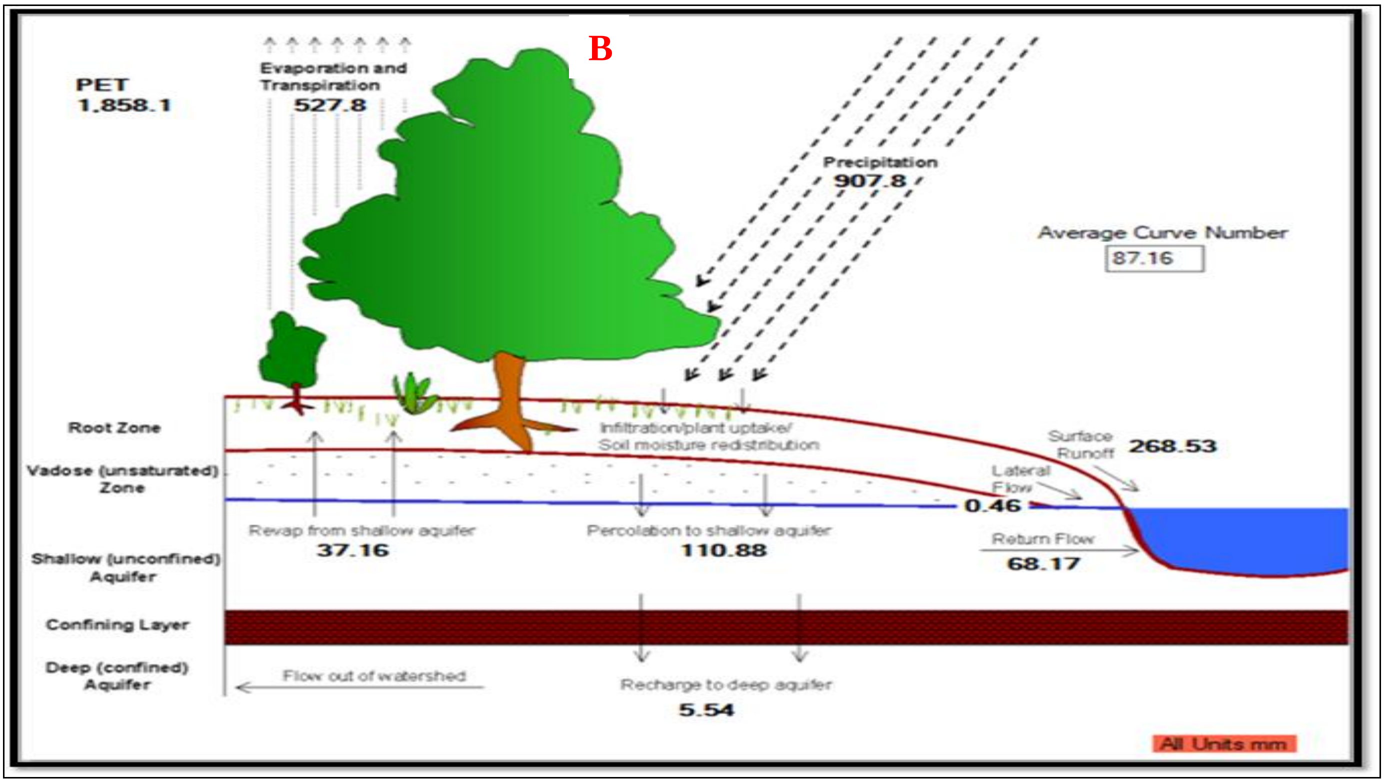

Fig 8: Water Balance Elements of the KPC Under Scenario-1I-(B)

- Runoff might take longer to reach the outlet in the more detailed model due to increased channel routing complexity, leading to higher infiltration and evaporation losses.
- The more subdivided model may better capture attenuation effects, where the flow is slowed down and spread out and reducing peak runoff.

Table 4 illustrates the monthly hydrological data for an 11-sub-basin catchment and a 23-sub-basin catchment. The highest rainfall, 260.96 mm, was recorded in July. The surface flow was consistently higher in the 11-sub-basin catchment compared to the 23-sub-basin catchment, with the highest values also observed in July (89.60 m^3/s for the 11-sub-basin catchment). Similarly, the water yield was highest in the 11-sub-basin catchment, particularly in July (88.57 mm). The evapotranspiration (ET) and potential evapotranspiration (PET) values were also generally higher in the 11-sub-basin catchment, with July showing ET values of 91.07 mm and PET values of 142.70 mm. Overall, the data confirm that the 11-sub-basin catchment exhibits higher values for surface flow, water yield, ET, and PET compared to the 23-sub-basin catchment. The tabular values are plotted in graphical format and shown in figure 6.

The graph shown in figure 6 illustrates that the evapotranspiration (ET) parameter increases during the summer months, while the intensity of rainwater and surface flow water yield remains low. Conversely, during the rainy season, the ET and potential evapotranspiration (PET) values decrease. During these months, the graph shows a corresponding increase in rainfall, surface flow, and water yield values. This pattern suggests a seasonal shift where higher temperatures and reduced rainfall in summer lead to increased evapotranspiration, while the rainy season's abundant precipitation results in lower evapotranspiration but higher surface water flow and overall water yield. Interestingly, there is no much variation shown in all the parameters of surface flow, water yield, ET and PET between lower sub-basins and higher sub-basins.

B. Surface-Runoff Estimation

The average monthly estimated water balance components of KatePurna catchment (KPC) is listed in table 4. Mohammad et al [18] The SWAT model was utilized to estimate surface runoff in the Dohuk Dam catchment, revealing that surface runoff accounts for up to 20% of the total rainfall. Khayyun et al.[19] developed a hydrological model for the Derbendi-Khan dam reservoir watershed using the SWAT model. Their findings revealed that the average annual snowmelt ratio was approximately 24% of the average annual precipitation during the simulation period. The hydrological simulation of a small ungauged agricultural watershed in Northern India, conducted using the SWAT model, indicated that surface runoff comprised approximately 36% of the total rainfall [20]. Emam et al. [21] utilized the SWAT model for hydrological modeling and runoff mitigation in two locations within an ungauged basin in central Vietnam. They discovered that the resulting surface runoff ranged from 22.5% to 26% of the total precipitation, attributing this variation to differences in slope between the two sites.

The table provides a detailed account of the annual average runoff and discharge values over a span of 29 years. It highlights that in 2006, the surface runoff and discharge were slightly higher for the 11 sub-basins catchment compared to the 23 sub-basins catchment. This increase is attributed to the higher precipitation recorded in that year. Conversely, in 2004, which experienced the lowest precipitation, the runoff and discharge were still greater for the 11 sub-basins catchment than for the 23 sub-basins catchment. This data underscores the variability in hydrological responses across different sub-basin catchments depending on annual precipitation levels.

The graph in Figure 7 illustrates that runoff values exceed discharge values in both scenarios examined for the KatePurna catchment. The peak values for both runoff and discharge coincide with periods of higher precipitation within the year. Specifically, the annual average precipitation was highest in 2006, which correlates with the observed higher runoff and discharge values for both scenarios involving more and fewer sub-basins within the KatePurna catchment. This indicates a direct relationship between increased precipitation and the subsequent rise in runoff and discharge, emphasizing the impact of rainfall on the hydrological dynamics of the catchment area.

Table 1: The Average Monthly Values of Water Balance Components for the KatePurna Catchment from SWAT Simulations Over the Period from 1995 to 2023

Month	Rain (mm)	Surface Q m^3/s		Water yield (mm)		ET, mm		PET, mm	
		Sub-23	Sub-11	Sub-23	Sub-11	Sub-23	Sub-11	Sub-23	Sub-11
1	9.82	0.75	0.75	1.62	1.63	13.58	13.54	124.35	125.87
2	6.27	0.04	0.04	0.49	0.49	12.48	12.41	142.20	143.84
3	14.88	1.06	1.07	1.43	1.44	50.75	50.94	196.03	197.22
4	9.13	0.05	0.05	0.32	0.32	46.54	46.66	221.43	222.75
5	15.71	0.21	0.21	0.39	0.38	12.16	11.99	234.21	235.59
6	158.56	14.21	14.31	14.22	14.27	59.48	59.71	175.69	176.69
7	260.96	88.99	89.60	88.38	88.57	90.64	91.07	141.99	142.70
8	196.86	80.10	80.76	91.07	91.93	81.24	81.62	129.18	129.84
9	169.81	63.80	64.27	83.02	83.70	74.02	74.38	120.79	121.40
10	53.39	14.10	14.21	38.16	38.61	47.75	47.94	128.46	129.17
11	15.63	3.14	3.17	17.01	17.10	23.11	23.13	116.79	117.45
12	4.77	0.09	0.09	4.24	4.30	14.33	14.30	115.33	115.99

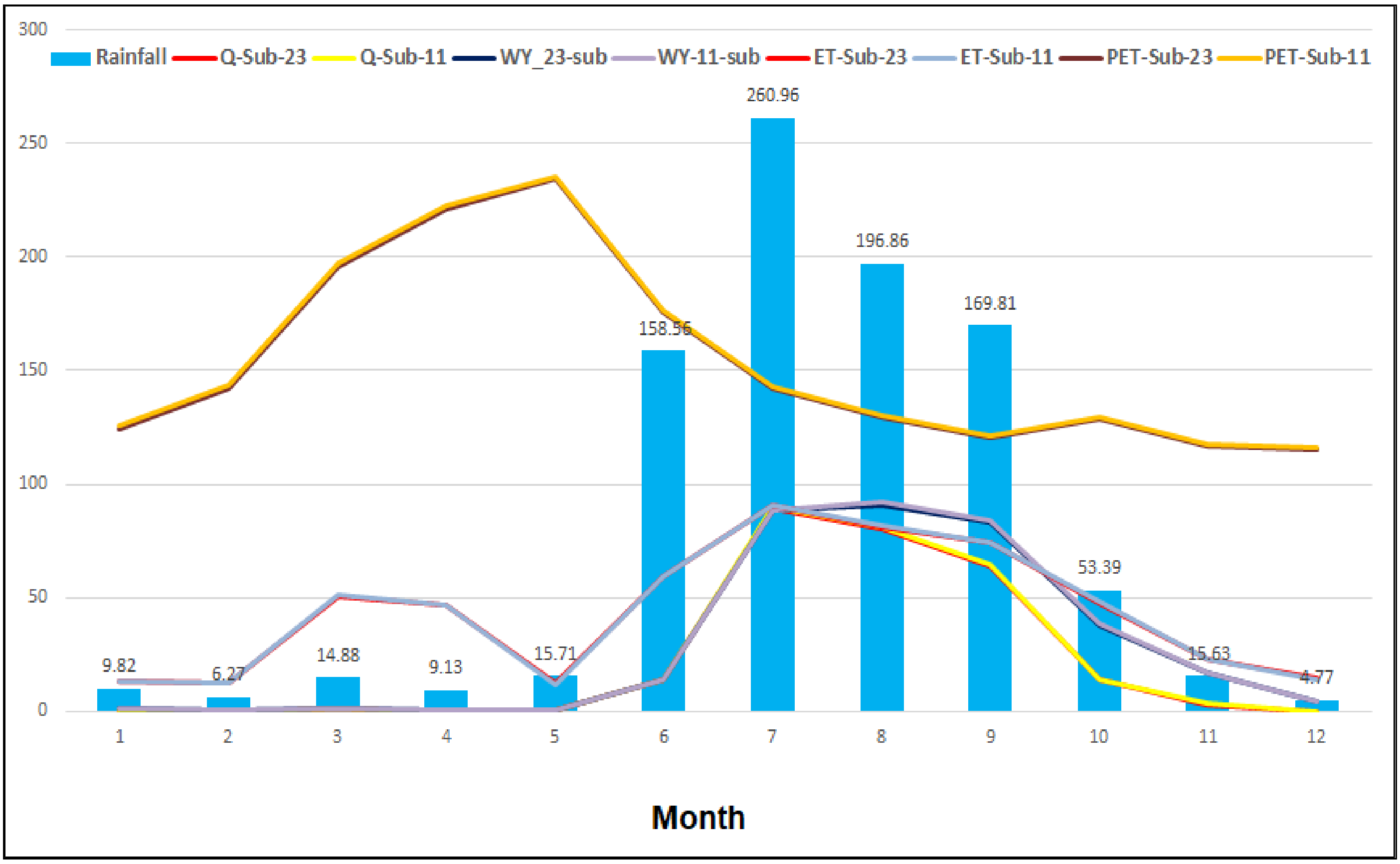

Fig 9: Graphical Representation of Hydrological Parameters as Per Table-4

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

The Soil and Water Assessment Tool (SWAT) model was employed for runoff and sediment yield estimation. Land use changes significantly influenced runoff and sediment yield patterns in the watershed and underscores the importance of effective land management practices to mitigate soil erosion and sediment transport in the watershed [22].

Table 2: The Annual Averages of Surface Runoff (SURQ), and Flow_Out for the KPC from 1995 to 2023

Year	Prec. (mm)	SURQ. (mm)		FLOW_OUT, (m^3/s)	
		23 basins	11 basins	23 basins	11 basins
1995	66.25	19.24	20.23	1.68	2.78
1996	59.90	13.47	13.61	1.27	2.08
1997	72.10	17.59	18.22	1.57	2.58
1998	84.38	25.85	25.53	2.82	4.63
1999	79.22	26.55	27.21	2.78	4.57
2000	59.46	15.86	15.91	1.50	2.45
2001	67.72	17.80	18.45	1.70	2.80
2002	62.44	16.95	17.90	1.62	2.67
2003	73.24	18.61	20.31	1.96	3.24
2004	53.14	7.43	7.83	0.63	1.04
2005	80.17	25.42	26.12	2.60	4.27
2006	113.08	50.26	50.31	5.14	8.40
2007	69.18	20.49	20.91	2.13	3.50
2008	56.60	10.84	11.67	1.11	1.84
2009	69.93	17.14	17.40	1.80	2.96
2010	95.32	32.45	33.20	3.75	6.15
2011	67.15	15.35	15.41	1.80	2.96
2012	74.48	23.37	24.16	2.52	4.14
2013	94.74	33.69	35.77	3.70	6.08
2014	62.90	16.45	17.11	1.47	2.41
2015	81.84	29.21	30.12	2.71	4.45
2016	86.0	28.38	28.01	3.33	5.45
2017	60.52	11.28	10.38	1.17	1.92
2018	71.04	22.41	22.38	2.45	4.0
2019	80.94	21.46	21.07	2.87	4.69
2020	84.0	19.97	20.22	2.56	4.20
2021	101.56	35.18	35.10	4.21	6.88
2022	105.10	40.64	42.64	4.71	7.72
2023	77.00	21.75	23.19	2.78	3.75

VI. CONCLUSIONS

The SWAT model served as an effective tool for elucidating the components of the hydrologic cycle and identifying factors influencing the hydrological conditions both generally and specifically within the study area. The water yield projected by the simulation can be regarded as preliminary data, useful for formulating plans to optimize the utilization of these water resources. If these plans are executed, they could ensure a more stable water supply for the region, benefiting both the local population and the environment.

It is important to note that the model was not calibrated due to the absence of streamflow data from the nearby KatePurna catchment. Nonetheless, these preliminary results can effectively describe the water conditions in the area and provide an initial perspective on its hydrological situation. Once the necessary data for calibration becomes available, these results can be modified accordingly. Establishing a streamflow measuring station along the river section is a top priority, as it will create a realistic database that allows relevant authorities and researchers to make more accurate assessments and provide more reliable forecasts for future water projects in the region.

Additionally, the SWAT results can be viewed as a preliminary assessment that provides an overview of the area's hydrological conditions. They help build an initial understanding of the water system, identify its key components, and anticipate the factors that most significantly impact it. This information empowers policymakers, decision-makers, and stakeholders to formulate future research and implementation plans aimed at enhancing water investment in the region, especially in the context of climate extremes.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1061

REFERENCES

[1]. Arnold, J. G., Srinisvan, R., Muttiah, R. S., Williams, J. R., 1998. Large area hydrologic modeling and assessment. Part I: Model development. Journal American Water Resources Association, 34(1), 73-89.

[2]. Gassman, P. W., Sadeghi, A. M., Srinivasan, R., 2014. Applications of the SWAT model special section: overview and insights. Journal of Environmental Quality, 43(1), 1-8.

[3]. Aziz, Y. W., Hamah Saeed, M. A., Ahmed, S. S., 2020. Iraqi Geological Journal, 53(2E), 96-106.

[4]. Heedan, M. O., Bapeer, G. B., Khodakarami, L. 2017.Estimation the volume of runoff using natural resources conservation service method and geographic information system in Koya basin, Sulaimaniya, Iraq. Iraqi Geological Journal, 50, (2), 2017

[5]. Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., van Griensven, A., Van Liew, M. W., Kannan, N., &Jha, M. K.,2012. "SWAT: Model Use, Calibration, and Validation", Transactions of the ASABE (American Society of Agricultural and Biological Engineers), 55(4):1227-1240.

[6]. Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R., 2011, , "Soil and Water Assessment Tool: Model Use, Calibration, and Validation", Journal of Hydrology, 409: 412-429

[7]. Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. 2007, Journal of Environmental Quality, "Model Use, Calibration, and Validation: SWAT Soil and Water Assessment Tool", 36(5): 1675-1662.

[8]. Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., & Srinivasan, R. 2007, "Soil and Water Assessment Tool: SWAT Model Use, Calibration, and Validation", Journal of Hydrology, 337: 3-24.

[9]. Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G., 2007, "Model Use, Calibration, and Validation: SWAT Soil and Water Assessment Tool", Journal of the American Water Resources Association,43(1): 135-149.

[10]. Aziz, N. A. A., Hassim, M. H., Yusof, K. W., Ali, M. R. M., & Rahman, N. A. A., 2018, "Application of the SWAT Model for Runoff Simulation and Sediment Yield Estimation in a Tropical Catchment", Journal of Sustainability, 10(2): 473-498.**doi**.org/**10.3390**/**su10020473**.

[11]. Nalubega, M., Tenywa, M. M., &Majaliwa, M. J. G., 2019, "Estimation of Runoff and Sediment Yield in the Upper Rwizi Catchment Using SWAT Model", Journal of Environmental and Public Health, 14:1-12.

[12]. Rong, W., Yubin, L., Ziqiang, L., Shaowei, L., Yipeng, Z., &Xueqin, Z., 2020, "Runoff Simulation and Analysis of the Impact of Climate Change on a Watershed Based on the SWAT Model", journal of Water, 12(4):1-15. doi: 10.3390/w12040982

[13]. Sonnenborg, T. O., Refsgaard, J. C., Jensen, K. H., &Jeppesen, E., 2021, "SWAT-MODFLOW—A Coupled Watershed–Groundwater Model: Description and Application to the Odense Pilot River Basin, Denmark", Journal of Water, 13(9): 1-23.doi: 10.3390/w13091267

[14]. Winchell, M., Srinivasan, R., Di Luzio, M., Arnold, J., 2010. Arc SWAT interface for SWAT 2009: User's guide. Temple, Tex.: Blackland Research and Extension Center, Texas AgriLife Research, and USDA-ARS Grassland, Soil, and Water Research Laboratory.

[15]. Li, E. A., Shanholtz, V. O., Contractor, D. N., Carr, J. C., 1977. Generating rainfall excess based on readily determinable soil and land use characteristics. American Society of Agricultural and Biological Engineerings , 20(6), 1070-1078.

[16]. Srinivasan, R., Zhang, X., Arnold, J., 2010. SWAT ungauged: Hydrological budget and crop yield predictions in the upper Mississippi River basin. American Society of Agricultural and Biological Engineerings, 53(5), 1533-1546.

[17]. Neitsch, S. L., Arnold, J., Kiniry, J., Williams, J., 2005. Soil and Water Assessment Tool Theoretical Documentation Version 2005. Texas A&M University System, College Station, TX, USA.

[18]. Mohammad, M. E., Al-Ansari, N., and Knutsson S., 2016. Application of SWAT model to estimate the annual runoff and sediment of Duhok reservoir watershed. 8th International Conference on Scour and Erosion, Oxford University.

[19]. Khayyun, T. S., Alwan, I. A., Hayder, A. M. 2020. Hydrological model for Derbendi-Khan Dam Reservoir Watershed Using SWAT Model, Engineering and Technology Journal, 38 (6), 896-909.

[20]. Mishra, H., Denis, D. M., Suryavanshi, S., 2017. Hydrological simulation of a small ungauged agricultural watershed Semrakalwana of Northern India. Applied Water Science, 7, 2803–2815.

[21]. Emam, A. R; Kappas, M; Linh, N. H. K; Renchin, T. 2017. Hydrological modeling and runoff mitigation in an ungauged basin of central Vietnam using SWAT model. Hydrology, 4 (1), 16.

[22]. Wu, J., Xu, H., Wu, J., Zhang, J., Zhao, D., & Qi, Z., 2017, "Estimation of runoff and sediment yield using the SWAT model in the Daning River watershed, China", Environmental Earth Sciences, 76(1):32-48