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Climate Change Impact Assesment on Hydrological Regime of Yamuna River Basin using GIS

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Abstract: Climatic variables such as maximum and minimum temperature, precipitation are some of the important parameters that effect hydrologic process. Impact of these variables on hydrology at basin scale is important for efficient management of water resources. Extensive studyhas been carried out at watershed and river basin scale to understand the changes due to climatic variability and its effect on hydrological responses. Future climate scenario is best demonstrated by Regional Climatic Models (RCM). RCM estimates future climate variables in a better way. The resolution of RCM HadCM3 is $0.25^0X0.25^0$which can capture regional and local climate scenario and is therfore capable of simulating hydrological processes at watershed scale.To simulate the hydrology of the Yamuna river basin a hydrological model called Soil and Water Assessment Tool(SWAT)was used and analysis was carried out to studychanges on the hydrological regime of a basin due to climate change. The simulated average rainfall for 2005-2025 is in compliance with the average annual rainfall for 1970-2004 over the Yamuna basin with an overall increase of 3.8%. The estimated average surface runoff of 233.57 mm for the year 2005-2020 is found to increase by 6.1% than that of 1970-2004 when averaged over the entire basin.Water balance scenario for different time periods (1970-2004), (2005-2025) and (2026-2050) hasbeen generated for RCM HadCM3 dataset. Only the meteorological forcing was changed during simulation, vegetation and soil parameter were kept same to remove the effects of land use change. An increase in runoff was observed over the years. The evapotranspiration variation over the different scenario has been examined. In this way impact of climatic variability on hydrological regime wass analyzed in this study.
Keywords: Regional Climatic Model,, hydrologic simulation, SWAT hydrological model, Water balance Scenario

I. INTRODUCTION

On the global level the importance of fresh water to our life system is widely recognised. Fresh water is needed for almost all human activities that is in large quantities and hence it is indispensable. Due to complex interlinking between climate, freshwater, biophysical and socio economic system if we make changes to any one of them it will disturb the other. Researches on anthropogenic climate change have added a lot of pressure on those countries which were already facing problems regarding the sustainable use of freshwater. There are various challenges we face related to freshwater like having disproportionate amount of water, having too much pollution. Each of the above mentioned problems may get worsened due to climate change. Therefore it is of our primary concern to study the relationship between climate change and water resources. According to the reports published by Intergovernmental Panel for Climate Change (IPCC) eleven of the twelve years (1995-2005) rank among the twelve warmest years in the instrumental record of global surface. The linear warming trend over the past 50 years (1956-2005) is nearly twice that for 100 years (1906-2005). The report concluded that there was increase in the average temperatures in the 20th century and the factors leading to this problem in were increase rate of industrialization, deforestation and burning of fossil fuels. Due to the above mentioned factors the atmosphere had increase in the concentrations of green house house gases. The changein the balance of the greenhouse gases resulted in climate change in end of 20th century and early 21st century. Impact of climate change on future water resource of the basin need to be studied because of the change in rainfall pattern. The changes in climate resulting in the change in rainfall pattern may adversely affect the future water resources availability in basin ([1],[4],[9],[18]). Basins are sensitive to changing climate which can change plant growth rates, runoff and affect future water resources [19]. It is noticed that the rate of evapotranspiration are altered when the leaf area or stomatal changes which general occurs with change in carbon dioxide concentration in atmosphere. Crops in the basins will be highly affected due to the change in temperature, precipitation and atmospheric carbon dioxide. All these factors together play a major role on the availability of water resources of a region and due to this we need to study hydrology at basin scale. Climate change and global warming is a global phenomena and hydrology of basin is very sensitive to it. To study the hydrology of the basin and how it changes

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due to climate change SWAT was used. This model was used to assess the impact on the Yamuna river basin. The objective of the study was to study the change in pattern of the surface runoff due to change in climate for (2005-2025) and (2025-2050) and to study the water balance for the given periods. The study has practical implementations on water development, policy making and management under climate change constraints.

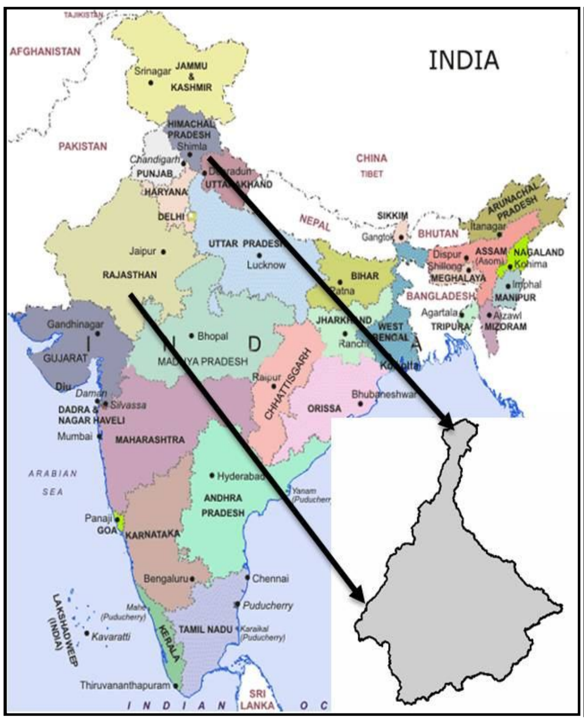
II. STUDY AREA

The study has been conducted for the Yamuna river basin which is a sub basin of Ganga river basin and is located in North Western part of India as shown in Fig. 1. The basin under study is bounded between 22.50° N to 32.00° N latitude and 73.20° E to 81.50° E longitude. The basin covers a total area of 3,66,233 sq km which is approximately 10.7% of Ganga basin. The basin experiences a great variation in the elevation of land surface ranging from 62m to 6288m above mean sea level. The mouth of the Yamuna river is at Yamunotri glacier near Banderorich peaks in the Mussorie range in Uttarakhand state of India. Yamuna basin covers the following states in its boundary Himachal, Haryana, Rajasthan, Madhya Pradesh , Uttar Pradesh and Uttrakhand. The percentage of the area covered by the states is shown in the Fig. 2.Yamuna basin has great spatial variation in its annual rainfall varying from 400 to 1200mm. It is noticed that basin is highly influenced by south west monsoon and this helps in replenishing the basin during the months of June to September. Winter rainfall in this region is very less. The rainfall distribution shows an increasing trend from North West to South East direction. The climatic condition of the basin can be broadly classified in three categories:

A. Humid : for upstream Himalayan catchmen

B. Semi Arid: North West to Western catchmen

C. Sub Humid: South West catchments



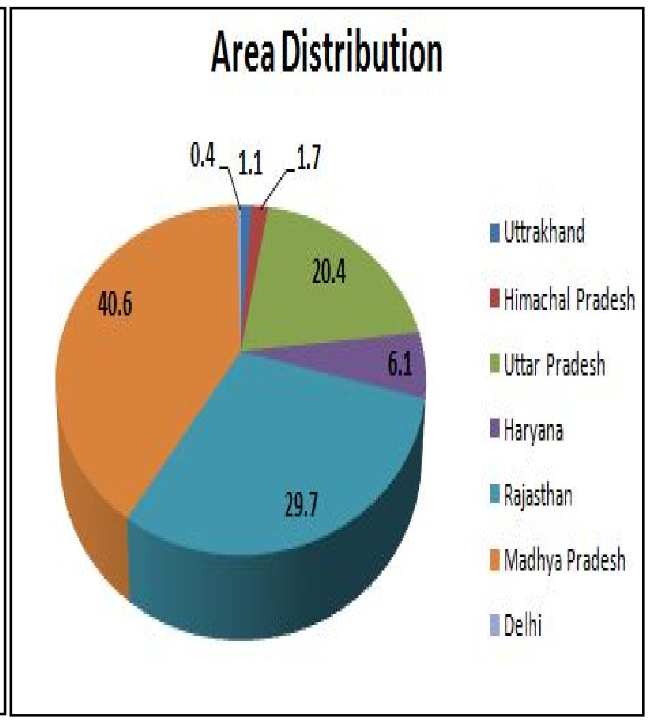


Fig. 1: Location of Study AreaFig. 2: State wise share of Yamuna River Basin

The mean maximum temperature of the basin varies from 24°c to 42.4°c and mean minimum temperature of -1°c to 11.0°c.

III. METHODOLOGY

SWAT Model:Soil and Water Assessment Tool(SWAT) is a conceptual and physical based model. It is a model which was developed by Dr Jeff Arnold which works efficiently at a river basin or watershed scale. The model does not incorporate any regression equations to establish relationships between various variables. SWAT requires input data like weather, soil properties, topography, land management practices and vegetation occurring in the the watershed. Using these input data SWAT is able to directly model the physical process associated with water movement, sediment movement, crop growth etc. The model is capable to predict the impact of climate change, land management practices on water resources, chemical yield and sediment. The simulation performed by the model helps the modeller to create number of sub watersheds of the basin by inputting a user defined input threshold area. Once the basin is divided in to number of watersheds it is further divided into multiple Hydrologic Response Units (HRU's) which have similar hydrologic response unit.SWAT helps in estimation of the streamflow by utilising various input data like Digital Elevation Model (DEM) of the basin for delineating the watershed, land use land cover maps coupled with weather data. The following weather inputs are required by the model:

A. Precipitation
B. Maximum and Minimum Temperature
C. Solar Radiation
D. Relative Humidity
E. Wind Speed

Overall hydrologic balance is simulated by the model for all the HRU's generated. Model Setup:The study uses various spatial data which includes digital elevation model , Land use land cover map, soil map, meteorological data, stream gauge data.The DEM used in the study was Shuttle Radar Topography mission with a resolution of 90m. The data was downloaded from the website srtm.csi.cgiar.org The threshold area was decided and it was used for delineating the basin into various sub watersheds. The threshold used in the study was 200000 ha. The creation of subwatershed is shown in the Fig. 3 . After creation of subwatershed the model creates the HRUS's using the land use, soil and slope characteristics. For creation of the HRU's threshold percentage of land use, soil and slope factors were taken as 5%, 10% and 15% respectively. The following methods were used for the calculations:Land Use Land Cover map used inthe study was developed by National Remote Sensing Centre, India at a resolution of 56mX56m.Regional Climate Model HadCM3 data from the year 1971-2050 was utilised for the weather data in the model . The grid size of the précis data is 0.25°X 0.25°. Total 513 mnumber of grid points fallin the basin.The grid points are shown in the Fig. 4:

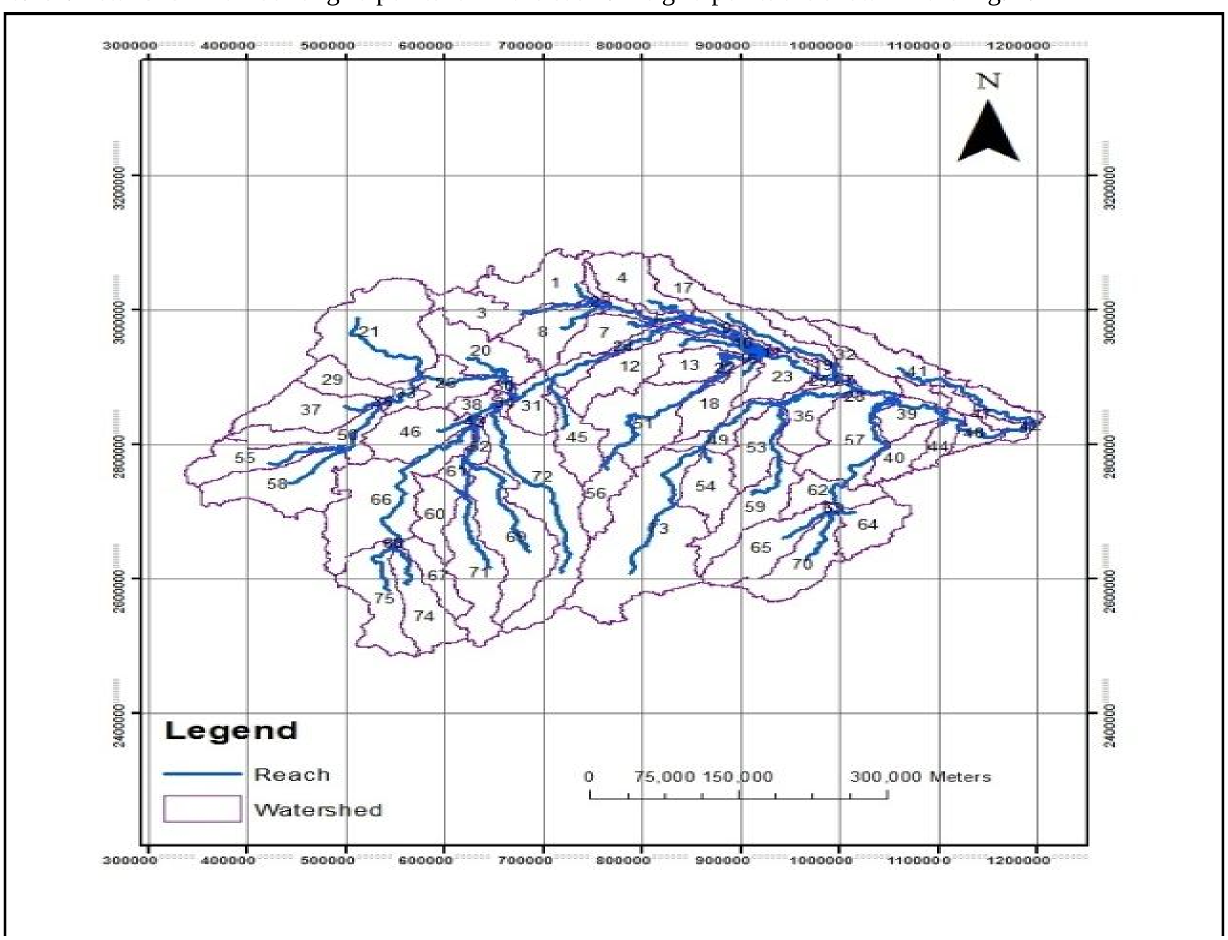


Fig. 3 : Watershed Deliniation

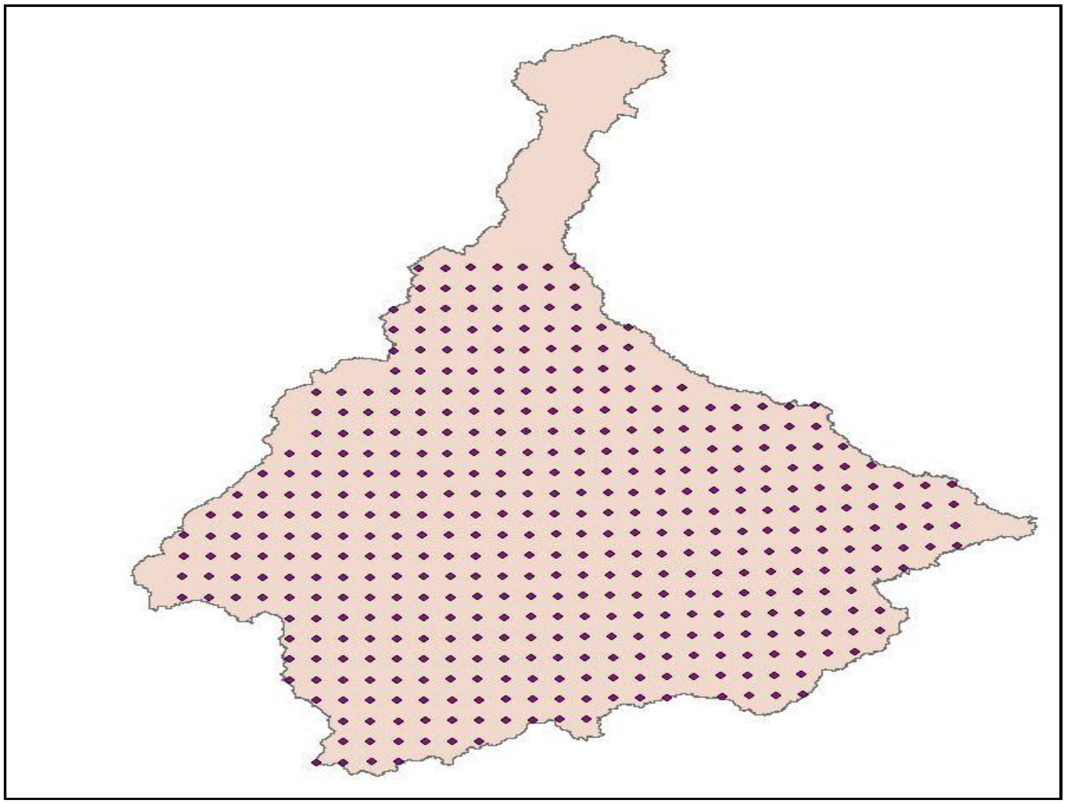


Fig. 4: RCM HadCM3 Grid Point

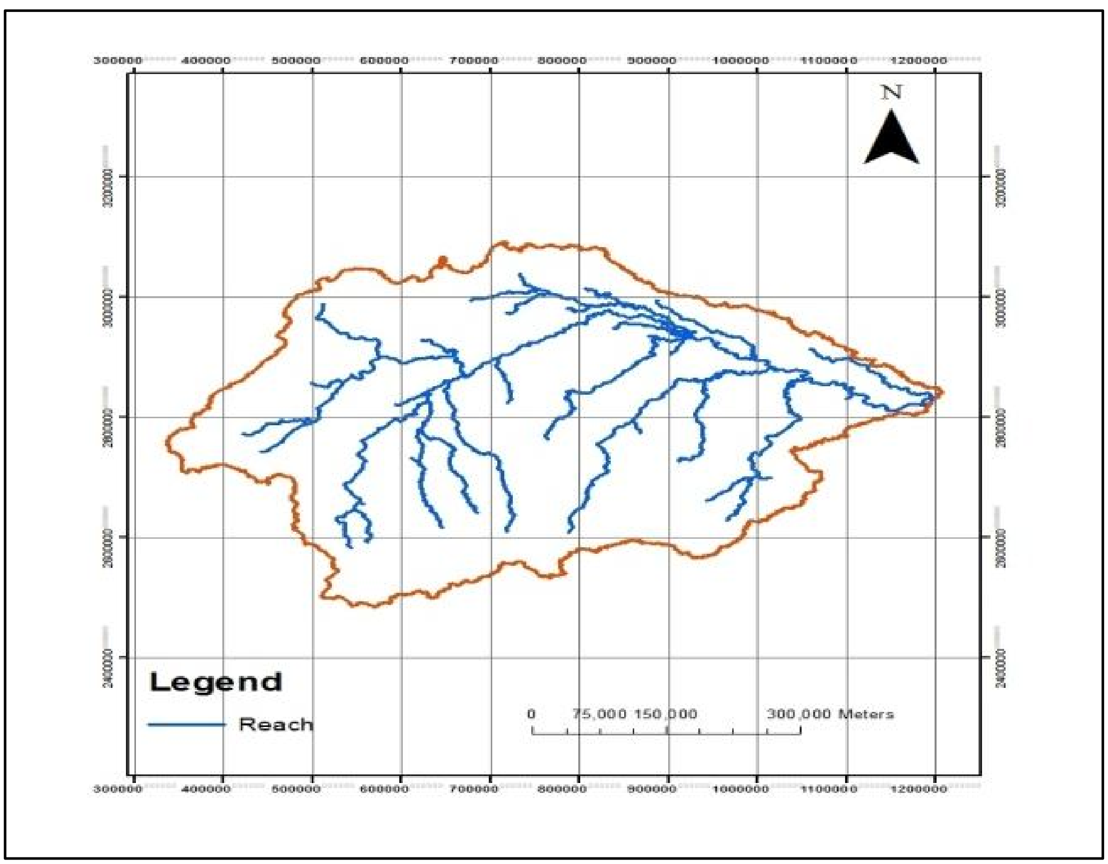


Fig. 5 : Stream Network generated by SWAT

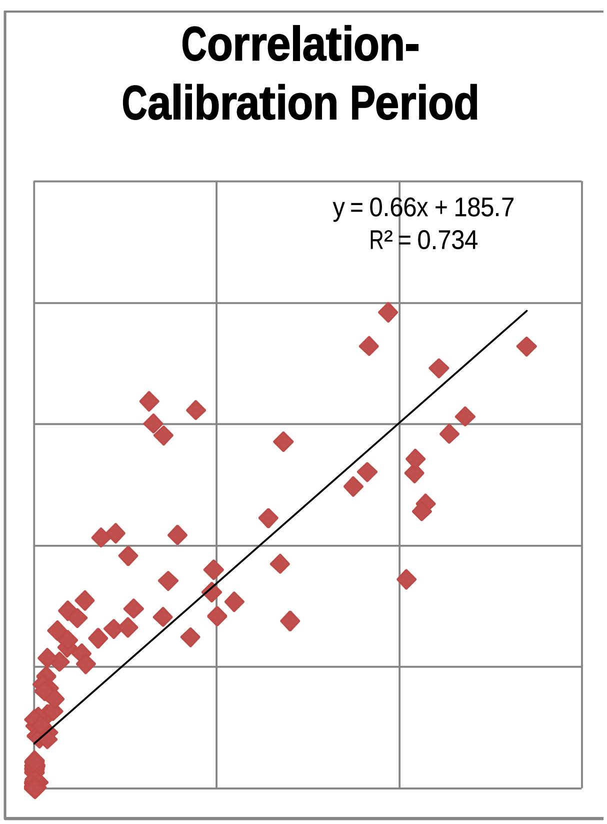
IV. CALIBRATION AND VALIDATION OF SWAT MODEL

The model was calibrated using the observed monthly stream flow for the year of 1971-1990 for a gauging site named "X". Process of calibration was carried out manually by altering the various model parameters within the limits defined in the SWAT manual. The model was validated by using the observed monthly stream flow for gauging site "X" from the period 1990-2005. The performance of the model was measured by the help of statistical comparisons on the basis of Nash-Sutcliffe coefficient and coefficient of determination.

Nash- Stutcliffe coefficient (NS):The efficiency of the SWAT model is measured with the help of Nash- Stutcliffe coefficient. The coefficient was calculated by relating the variance of the observed data and the goodness of fit of the model and it can range between -∞ to 1. If the value of the coefficient is 1 it indicates a perfect match of the observed and simulated discharge. If the value is 0 it indicates that the simulate discharge are as accurate as the mean of the observed data, whereas value of coefficient less than zero indicates that the observed mean is better predictor than the model. According to various studies it was know that if the value of the coefficient ranges between 0.6 to 0.8 the model gives satisfactory results, whereas model performs well if the value is 0.9 and results are extremely good if the value of the coefficient is 1.

V. RESULTS AND DISCUSIONS

Calibration and Validation of Streamflow:SWAT model developed for the Yamuna river basin was calibrated and validated. The main objective of the method is to maximise the model efficiency. The time series plot of monthly observed and simulated streamflow for calibration and validation period are shown in the Fig.6 and 7 respectively.Monthly observed and simulated stream flow data was compared for gauging site "X". The estimated stream flow shows trend similar to that of observed stream flow in both calibration and validation period. The model showed satisfactory simulation results. Statistical comparison was performed for the observed and simulated stream flow data for calibration and validation period. Nash Sutcliffe coefficient and coefficient of determination was calculated for both the periods. The results obtained were within acceptable range, as shown in Table 1 and was considered for further analysis of impact of climate change on the river basin. The NS and $R^2$are shown in the table. A scatter plot between monthly observed and simulated stream flow for calibration and validation period are shown in Fig. 8 and 9 respectively.



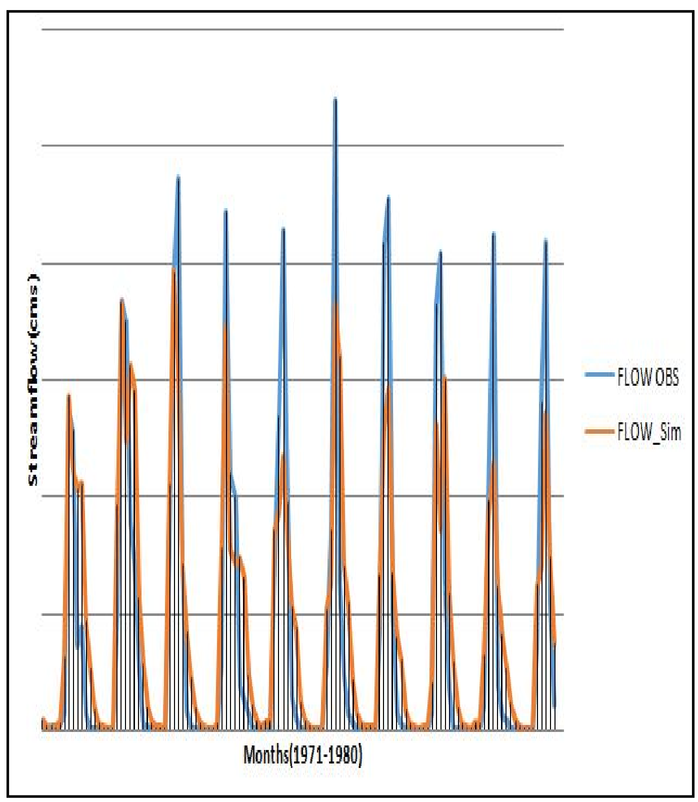


Fig. 6: Scatter Plot for Calibration PeriodFig. 7: Callibration of Model

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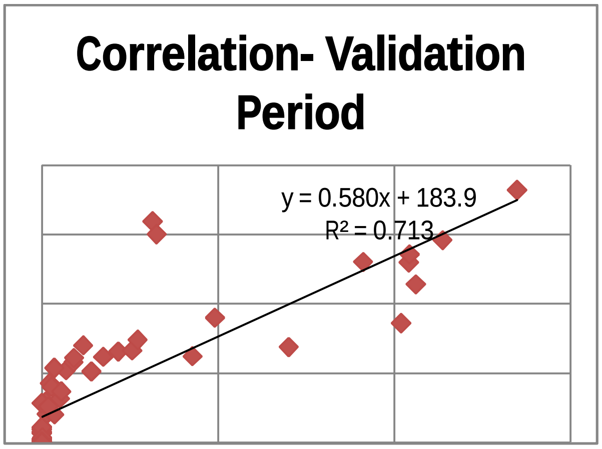

Fig. 8: Scatter Plot for Validation Period

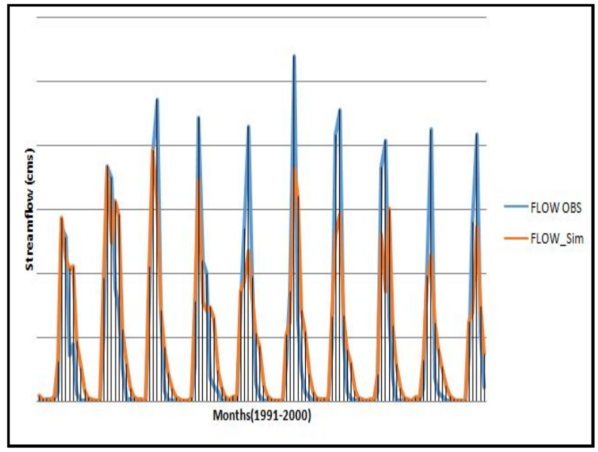

Fig. 9: Validation of Model

Table 1 : Statistical Parameters

Statistical Parameters	Calibration Period	Validation Period
Nash-Sutcliff Coefficient (NS)	0.692	0.756
Coefficient of Determination (R^2)	0.734	0.713

Fig. 10 a shows the average monthly streamflow for the months May to Sep for the base period (1971-2005), (2006-2025) and (2026-2050).Similarly the average monthly streamflow for the months of (Jan- March) is shown in the Fig. 10 b . The results clearly show that the basin is highly dependent on monsoon rainfall.

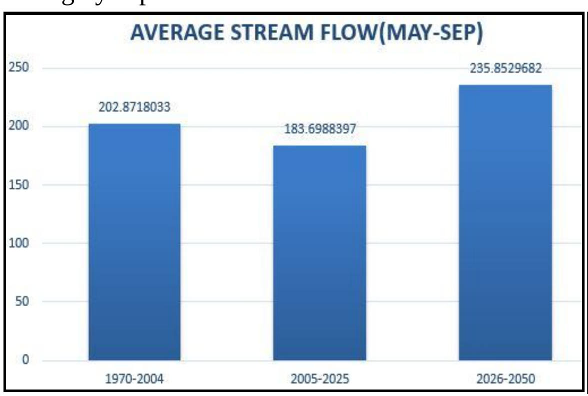

Fig. 10 a : Average stream flow for month (May-Sep)

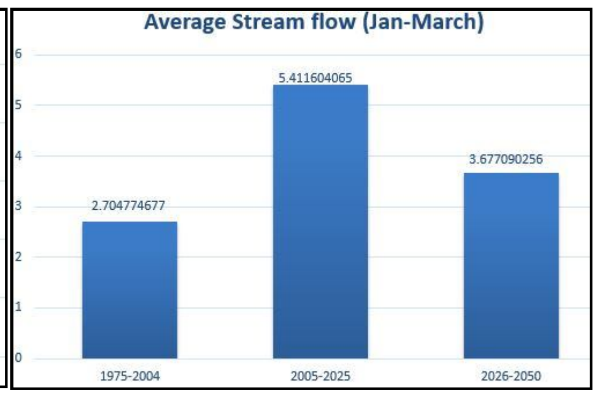

Fig. 10 b: Average stream flow for month (Jan-March)

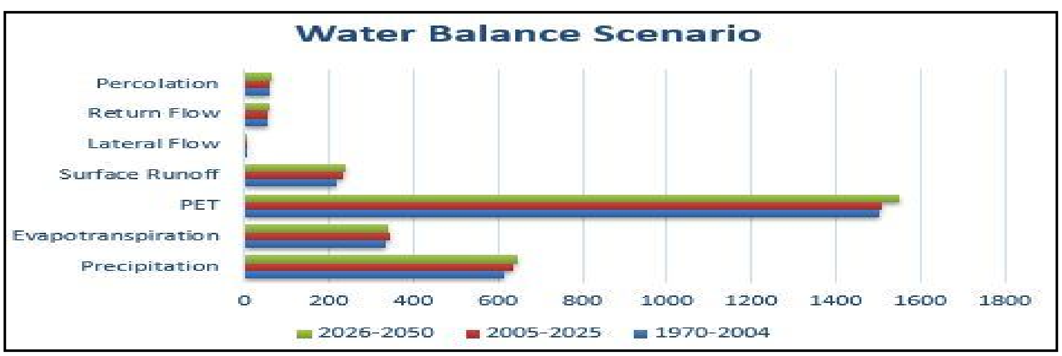

Fig. 11: Water Balance Scenario

Water balance scenario has been shown in the Fig. 11. The fig. shows how the PET, Evapotranspiration, streamflow and precipitation will be varying in the future. The simulated average rainfall for 2005-2025 is in compliance with the average annual rainfall for 1970-

2004 over the Yamuna basin with an overall increase of 3.8%. The estimated average surface runoff of 233.57 mm for the year 2005-2020 is found to increase by 6.1% than that of 1970-2004 when averaged over the entire basin.

From the result it is obvious that for the period (2026-2050) precipitation will increase and evapotranspiration will decrease leading to increase in streamflow in the basin. Streamflow for the month of (Jan- March) and (May-Sep) for the base period (1971-2004) ,(2005-2025) and (2026-2050) are shown in the Fig. 12 (a)and Fig. 12(b) respectively.

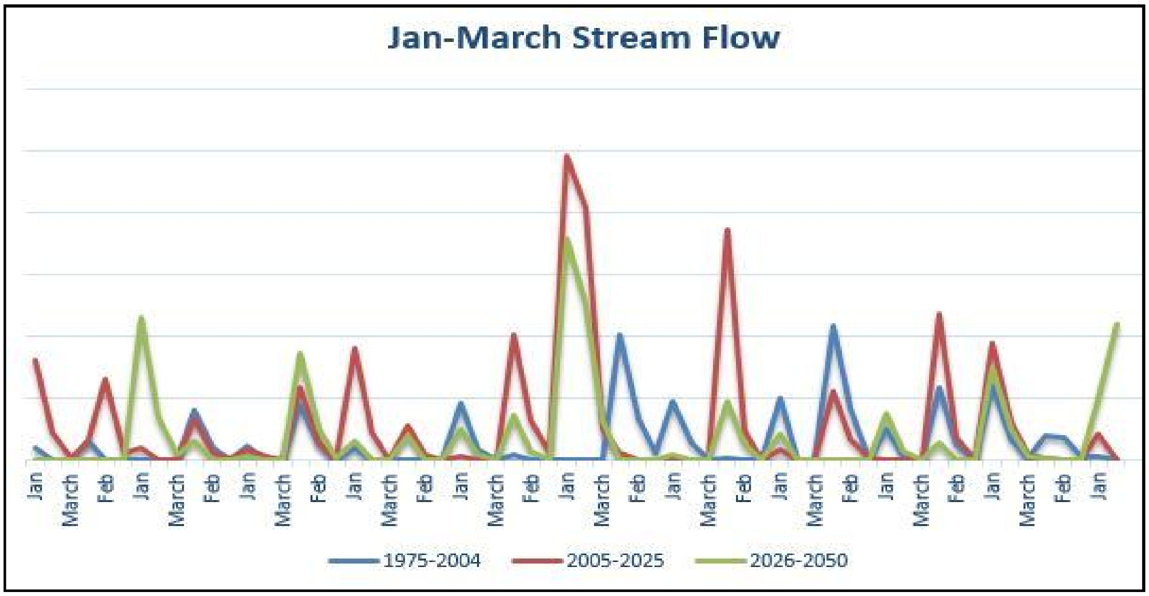

Fig. 12 (a) : Stream flow for the months of (January-March)

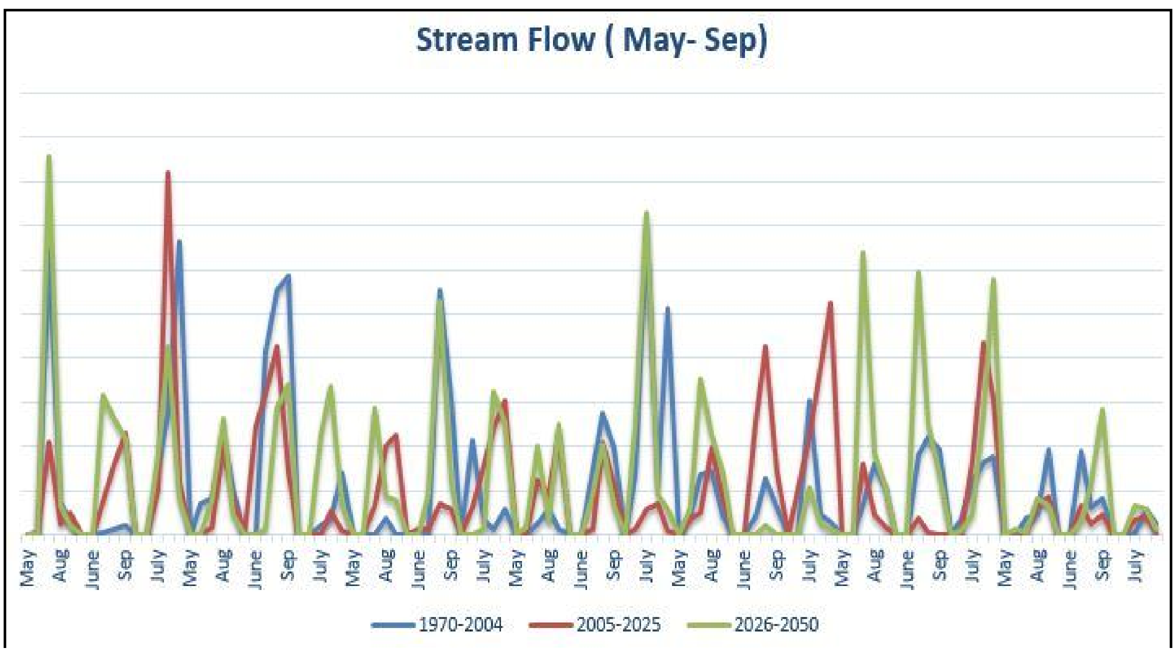

Fig. 12 (b) : Stream flow for the months of (May-September)

VI. CONCLUSION

It was a challenging task for quantifying impact of climate change where water balance simulation modeling approach has been used to maintain the dynamics of hydrology and therefore making assessments more reliable. By analyzing the results obtained from the study on impact of climate change on hydrological regime of Yamuna river basin, it is clear that SWAT model does perform well for simulating the stream flow by mimicking the hydrological aspects of the river basin. While studying the impact of climate change on basin hydrology it was observed that stream flow is sensitive to evapotranspiration and precipitation and these factors change due to carbon dioxide concentration level in the atmosphere.Significant changes in the hydrological cycle can be observed for the future climate change scenarios. The analysis of the climate change will put more pressure on the government and will lead to development of new strategies to face the upcoming challenges. Various strategies like development in warning systems, change in cropping pattern, water conservation, change in land use can be incorporated. Results obtained from hydrological modelling can be used by the policymakers to make policies regarding water resources keeping climate change in mind. Similarly the results obtained can be very useful for conflict resolution and for fair allocation of water resources to various states sharing the common resource.

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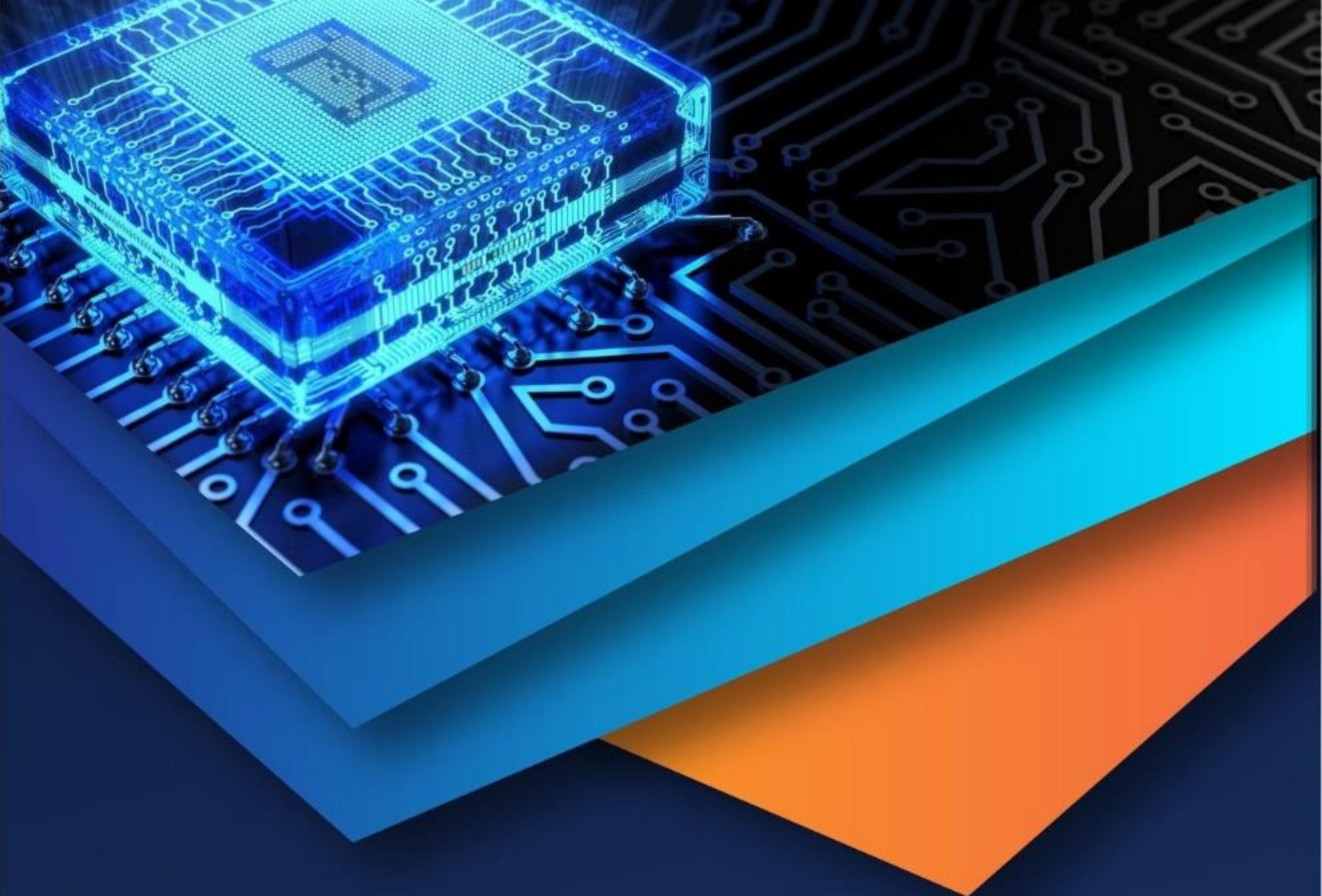

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