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# MODELING CLIMATE CHANGE IMPACTS ON RUNOFF IN UPPER NARMADA RIVER BASIN (M.P.) INDIA

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**Abstract-** Climate change would significantly affect many hydrologic systems, which in turn would affect the water availability, runoff, and the flow in rivers. The predicted intensification of hydrological cycle would change all of its constituents both in time and space domain. This is a long term phenomenon and the necessity is to understand the intensity of the effects on various aspects of water resources by way of scientific studies backed by the available field data. Therefore, in the present study, the impact of climate change on study area under different assumed plausible hypothetical scenarios has been studied. These scenarios were developed by increasing; temperature by 1, 2 and 3$^0$C; rainfall by 5, 10 and 15%; and then the combination of both. To carry out this analysis, Arc SWAT hydrological model has been investigated. It was found that slight change in climate may pose huge difference on the hydrological cycle and its component.

**Keywords**- Climate Change; Runoff Simulation; Baseline; Climate Scenarios

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## Introduction

The rainfall and temperature drive the hydrological cycle, influencing hydrological processes in a direct or indirect way. A large number of studies have been carried out to analyze the trends of variation in these parameters over India/Indian Subcontinent. The projections indicate that the warming would vary from region to region, accompanied by the increase and decrease in precipitation [2-4 and 12]. In addition, there would be a change in the variability of climate, and changes in frequency and intensity of some extreme climatic phenomenon.

Intergovernmental Panel on Climate Change [6] concluded that it is more than 90% likely that accelerated warming of the past 50-60 years is caused by the anthropogenic release of greenhouse gases, such as $CO_2$ [14]. Nearly all regions of the world are expected to experience a net negative impact of climate change on water resources and ecosystems. Intergovernmental Panel on Climate Change (IPCC) projects that the global mean temperature may rise between 1.4 to 5.8 °C by 2100 [6]. Future climatic scenarios for mid to end of the twenty first century, as simulated by Global Climate Models, also show a warming trend over the entire world. However, the intensity and characteristics of these impacts can vary significantly from region to region. The frequency of floods and droughts is expected to increase in most parts of the world, resulting in declining crop yield thereby increasing the risk of poverty and hunger [9].

Climate change affects the hydrologic cycle of a region through changes in the timing, amount and form of precipitation, evaporation and transpiration rates and soil moisture. This has touched all parts of the world, including India. India is a large developing country with nearly two -thirds of its population depending directly on the climate sensitive sectors such as agriculture, fisheries and forests. Thus, India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding and Implementation of the latest techniques [13]. Many studies have implemented the approach of using hydrological models for simulating different climate change scenarios such as variations in temperature, rainfall and $CO_2$ [5,8].

This study deals with modeling impacts of climate change on surface runoff in the central part of India using Soil and Water Assessment Tool (SWAT). It has emerged as a powerful tool to quantify the effects of climate change on water resources [7]. Arc SWAT is a physically-based, semi-distributed hydrologic model, which has proven to be an effective tool for assessing water resource and non - point source pollution problems for a wide range of scales and environmental conditions across the globe [11]. Such studies play a key role in improving the decision making for water resources planning and management. The major objectives of the study are: to project climate change impacts on surface runoff.

## MaterialsandMethods

### Study Area

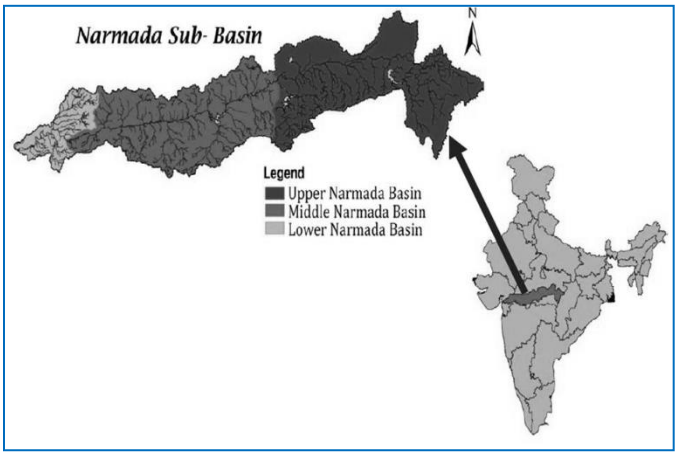
This study has been conducted in the upper Narmada basin. The Narmada river, rises in the Amarkantak Plateau of Maikal range in the Shahdol district of Madhya Pradesh at an elevation of 1057 meters above mean sea level at 22o40' North Latitude and 81o 45' East longitude. The tropic of cancer crosses the basin in the upper plains area and a major part of the basin lies just below this line. The climate of the basin is humid and tropical, although at places extremes of hot and cold are often encountered. Rainfall in the upper hilly areas, the average annual rainfall, in general is more than 1400mm but it goes up to 1650 mm. [refer Fig-1(a) and (b)]

### Hydrological Model

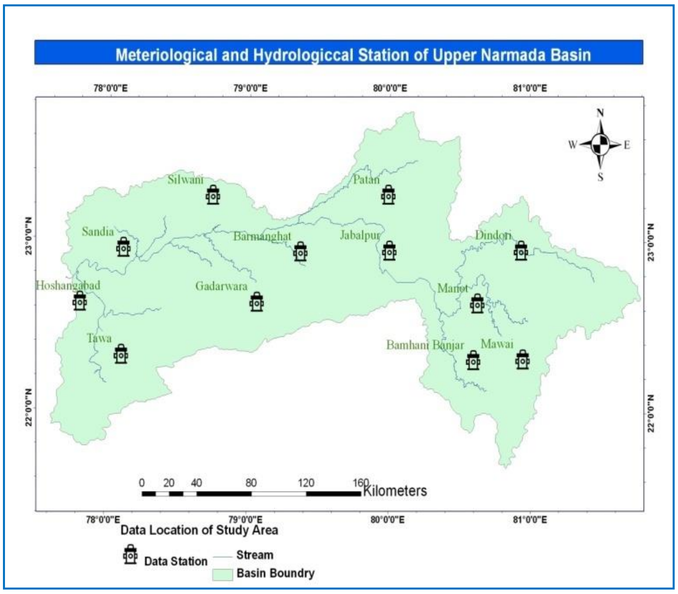
In this study ArcGIS interface of SWAT model version 2009 was used, which is physically-based, semi distributed and continuous time step model and used for predicting the impact of different LULC and climate change effect on hydrology and water quality of the watershed [11]. Arc SWAT simulates hydrologic cycle based on water balance. The general eq. is:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

Where, $SW_t$ = final soil water content (mm), $SW_o$ = initial soil water content (mm), t = simulation period (days), $R_{day}$ = amount of precipitation on the i$^{th}$ day (mm), $Q_{surf}$= amount of surface stream flow on the i$^{th}$ day (mm), $E_a$ = amount of evapotranspiration on the i$^{th}$ day (mm), $W_{seep}$ = amount of water entering the vadose zone from the soil profile on the i$^{th}$ day (mm), and $Q_{gw}$ = amount of base flow on the i$^{th}$ day (mm).




1(a)




1(b)

**Fig-1(a) Map of the study area and (b) Rain gauge location and streams**

Hydrology, weather, LULC and land management, crop growth, nutrient and, bacteria are the major components of ArcSWAT. The model calculates processes like stream flow, sediment and nutrients yield on HRU level. They are unique combinations of land use, land cover, soil type and slope classes. In the present study, 29 sub-basins and 272 HRUs were created which shows a satisfactory representation of the basin heterogeneity. The model uses an SCS Curve number (CN) method to estimate the surface runoff. Potential Evapotranspiration is estimated by using Hargreaves's Method.

### Input Data

The present study focuses on the application of SWAT 2009 in the Upper Narmada basin to observe the influence of climate change topographic; land use, soil and climatic condition etc. for that basic data required include three maps in GIS grid format. i.e., digital elevation model with spatial resolution 30X30 meter and Land use, land cover map Resources at-1 LISS-III remote sensing Image of October-November 2011 downloaded from http://bhuvan.nrsc.gov.in/data, which were processed in ERDAS IMAGINE 10 performed unsupervised classification method, Printed soil maps data of Madhya Pradesh at scale 1:5,00,000 were produced from National Bureau of Soil Science and Land Use Planning (NBSS&LUP), Nagpur. The available maps were scanned, rectified and digitized in Arc GIS to prepare the grid format map as required by arc SWAT. Weather data were downloaded from http://globalweather.tamu.edu.

### Climate Change Scenarios

According to various scenarios given by the Intergovernmental Panel on Climate Change (IPCC, 2007) the average surface temperature of the country could rise between 1 to 5 °C and rainfall increase from 5 to 20% over the area at the end of the 21st century [1,10].

Finally, we have selected average temperature rise between 1 to 3°C and rainfall increase between 5 to 15 % were selected and different simulations were carried out in the study area according to various scenarios of climate change. These scenarios are shown in [Table-1].

**Table-1** *Temperature and rainfall variation according to the climate change scenarios*

| Rainfall Increase (%) | Temperature Increase (° C) | Temperature Increase (°C) + Rainfall Increase (%) | | |
|---|---|---|---|---|
| 5 | T1 | T1+5 | T1+10 | T1+15 |
| 10 | T2 | T2+5 | T2+10 | T2+15 |
| 15 | T3 | T3+5 | T3+10 | T3+15 |

Where, T1= Increase temperature plus 1° C to base period, T2= Increase temperature plus 2 ° C to base period, and T3= Increase temperature plus 3° C to base period

### Results and Discussion

### Climate Change Analysis

The hydrological simulation of the entire UNB has been carried out using Arc SWAT model. Initial run was carried out for the base year 2011, which was normal rainfall year. It was found that the estimated runoff is in close agreement as per Indian conditions. The result for entire landmass of UNB in the base year, provided impetus to study the impacts of climate change by developing scenarios. It was found that runoff increased manifold with increase in overall rainfall percentage. However, increase in temperature due to urbanization, reduce the runoff generation slightly. The time series of estimated runoff of each scenario is presented in [Fig-2 (a, b, c)] with [Table-2 (a, b, c)]. It can be easily noted that with the increase in rainfall, the runoff increases manifolds, whereas, increase in temperature reduces runoff slightly. Simultaneously, an analysis to study the effect of climate change on evapotranspiration (ET) and Water Yield for the developed scenarios has also been carried out. The summary of results is presented in table and figure with [Table-3 (a, b, c)] and [Fig-4(a, b, c)] with [Table-4 (a, b, c)]. It can be seen that ET is showing increasing trend while in case of water yield increase in rainfall percentage increase but decreases in temperature increase.

**Table-2(a)** *Runoff estimation analysis of each scenario for winter*

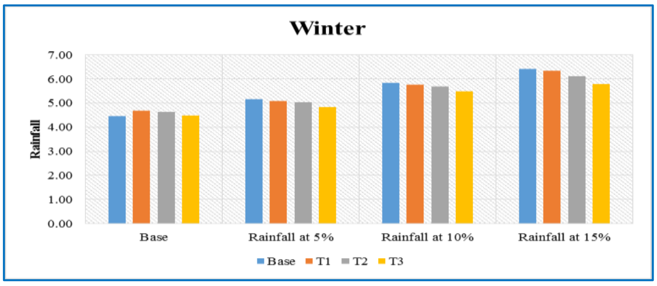
| Winter | | Increment in Rainfall | | | | Change | | | % Change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (ºC) | Base | 4.69 | 5.15 | 5.83 | 6.41 | -0.45 | -1.14 | -1.71 | -9.67 | -24.26 | -36.50 |
| | T1 | 4.63 | 5.08 | 5.75 | 6.34 | -0.46 | -1.13 | -1.71 | -9.85 | -24.39 | -37.07 |
| | T2 | 4.48 | 5.03 | 5.70 | 6.10 | -0.55 | -1.22 | -1.62 | -12.27 | -27.11 | -36.18 |
| | T3 | 4.46 | 4.83 | 5.47 | 5.78 | -0.37 | -1.01 | -1.32 | -8.35 | -22.75 | -29.69 |

**Table-2(b)** *runoff estimation analysis of each scenario for summer*

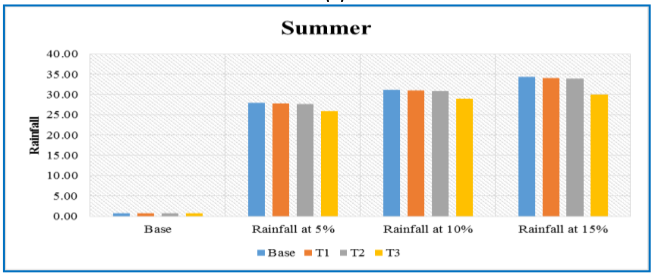
| Summer | | Increment in Rainfall | | | | Change | | | % Change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (ºC) | Base | 0.8 | 27.96 | 31.19 | 34.28 | -27.16 | -30.39 | -33.48 | -3395.00 | -3799.00 | -4244.00 |
| | T1 | 0.76 | 27.73 | 30.93 | 33.99 | -26.96 | -30.17 | -33.23 | -3547.00 | -3970.00 | -4668.00 |
| | T2 | 0.75 | 27.65 | 30.86 | 33.93 | -26.91 | -30.11 | -33.18 | -3588.00 | -4015.00 | -4784.00 |
| | T3 | 0.74 | 25.95 | 28.98 | 29.92 | -25.21 | -28.24 | -29.18 | -3407.00 | -3816.00 | -4604.00 |

**Table-2(c)** *runoff estimation analysis of each scenario for monsoon*

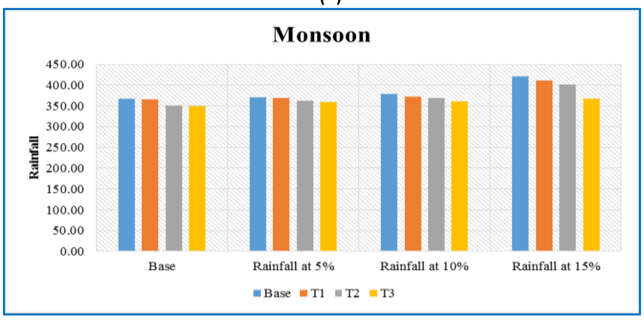
| Monsoon | | Increment in Rainfall | | | | Change | | | % Change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (ºC) | Base | 366.32 | 370.03 | 379.24 | 421.27 | -3.71 | -12.92 | -54.95 | -1 | -4 | -15 |
| | T1 | 365.32 | 368.51 | 372.12 | 411.57 | -3.19 | -6.8 | -46.25 | -1 | -2 | -13 |
| | T2 | 351.25 | 362.25 | 368.12 | 400.61 | -11 | -16.87 | -49.37 | -3 | -5 | -14 |
| | T3 | 349.8 | 359.8 | 360.16 | 367.67 | -10 | -10.36 | -17.87 | -3 | -3 | -5 |




2 (a)

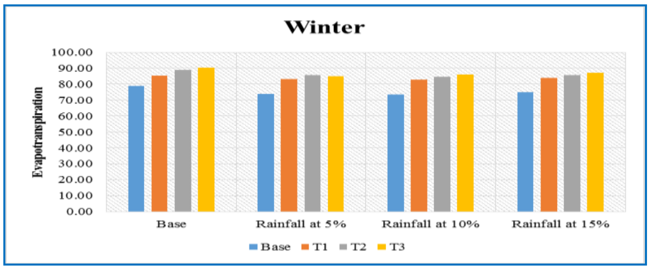



2 (b)

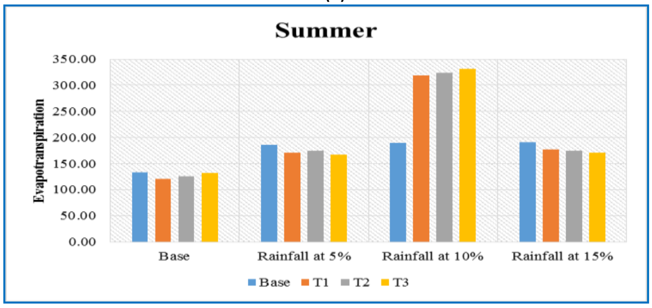



2 (c)

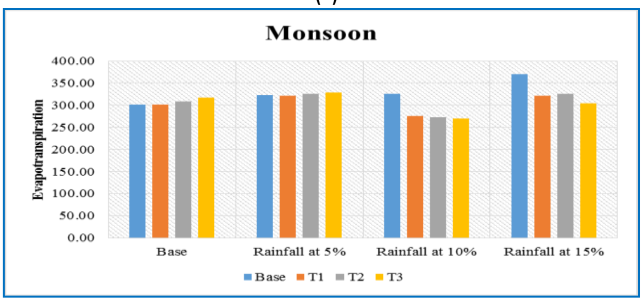
Fig-2 (a, b, c) Time series of estimated runoff of each scenario (Season wise)




3 (a)




3(b)




3 (c)

Fig-3 (a, b, c) Time series of estimated Evapotranspiration of each scenario (Season wise)

**Table-3 (a)** *Evapotranspiration estimation analysis of each scenario for winter*

| Winter | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (ºC) | Base | 78.85 | 73.79 | 73.42 | 74.90 | 5.06 | 5.43 | 3.94 | 6.41 | 6.88 | 5.00 |
| | T1 | 85.38 | 83.30 | 82.90 | 83.97 | 2.08 | 2.48 | 1.41 | 2.44 | 2.91 | 1.65 |
| | T2 | 88.95 | 85.61 | 84.49 | 85.61 | 3.34 | 4.46 | 3.34 | 3.75 | 5.01 | 3.75 |
| | T3 | 90.42 | 84.82 | 86.08 | 87.26 | 5.60 | 4.34 | 3.16 | 6.20 | 4.80 | 3.50 |

**Table-3(b)** *Evapotranspiration estimation analysis of each scenario for summer*

| Summer | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (°C) | Base | 133.51 | 186.08 | 189.06 | 191.12 | -52.57 | -55.55 | -57.62 | -39.38 | -41.61 | -43.16 |
| | T1 | 120.25 | 170.34 | 318.64 | 177.09 | -50.10 | -198.39 | -56.85 | -41.66 | -164.99 | -47.28 |
| | T2 | 124.88 | 174.60 | 323.51 | 174.60 | -49.72 | -198.63 | -49.72 | -39.81 | -159.06 | -39.81 |
| | T3 | 131.37 | 166.92 | 331.37 | 170.99 | -35.55 | -200.00 | -39.63 | -27.06 | -152.25 | -30.17 |

**Table-3 (c)** *ET estimation analysis of each scenario for monsoon*

| Monsoon | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (°C) | Base | 301.18 | 323.03 | 325.83 | 370.46 | -21.85 | -24.65 | -69.28 | -7.25 | -8.18 | -23.00 |
| | T1 | 300.45 | 320.93 | 275.10 | 320.87 | -20.48 | 25.35 | -20.42 | -6.82 | 8.44 | -6.80 |
| | T2 | 308.16 | 325.80 | 272.63 | 325.80 | -17.64 | 35.53 | -17.64 | -5.72 | 11.53 | -5.72 |
| | T3 | 317.18 | 328.72 | 269.10 | 303.73 | -11.54 | 48.08 | 13.45 | -3.64 | 15.16 | 4.24 |

**Table-4(a)** *Water yield estimation analysis of each scenario for winter*

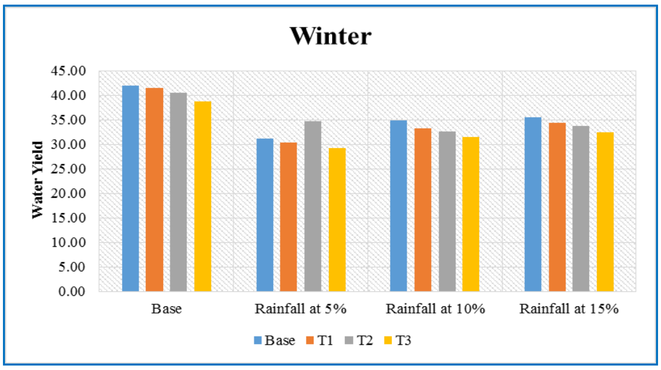
| Winter | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (°C) | Base | 41.95 | 31.06 | 74.81 | 33.42 | 10.89 | -32.86 | 8.53 | 25.96 | -78.34 | 20.33 |
| | T1 | 41.41 | 30.32 | 33.21 | 35.33 | 11.09 | 8.20 | 6.08 | 26.79 | 19.80 | 14.68 |
| | T2 | 40.44 | 34.71 | 32.62 | 34.71 | 5.73 | 7.82 | 5.73 | 14.16 | 19.34 | 14.16 |
| | T3 | 38.71 | 29.12 | 31.38 | 33.42 | 9.59 | 7.33 | 5.28 | 24.77 | 18.94 | 13.65 |

**Table-4(b)** *Water yield estimation analysis of each scenario for summer*

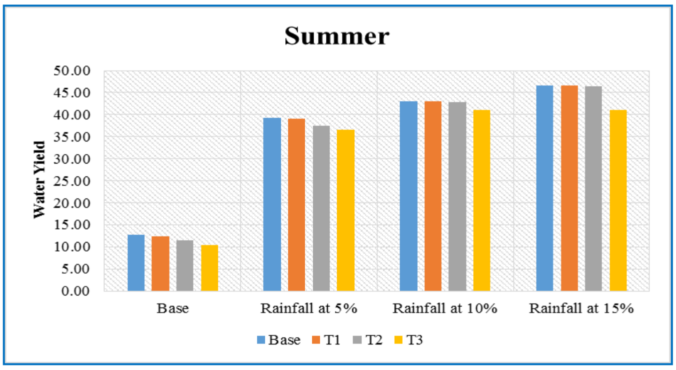
| Summer | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (°C) | Base | 12.80 | 39.23 | 43.00 | 46.61 | -26.42 | -30.20 | -33.80 | -206.37 | -235.87 | -263.99 |
| | T1 | 12.38 | 39.13 | 42.96 | 46.55 | -26.75 | -30.57 | -34.17 | -215.97 | -246.87 | -275.90 |
| | T2 | 11.38 | 37.53 | 42.89 | 46.47 | -26.14 | -31.50 | -35.09 | -229.62 | -276.71 | -308.21 |
| | T3 | 10.33 | 36.47 | 41.02 | 41.12 | -26.15 | -30.69 | -30.80 | -253.21 | -297.24 | -298.24 |

**Table-4(c)** *Water yield estimation analysis of each scenario for monsoon*

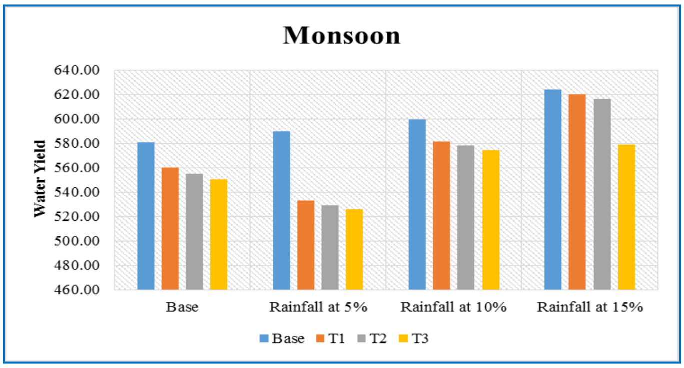
| Monsoon | | Increment in Rainfall | | | | Change | | | % change | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | 5% | 10% | 15% | 0-5 | 0-10 | 0-15 | 0-5 | 0-10 | 0-15 |
| Increment Temperature (°C) | Base | 580.77 | 589.50 | 599.12 | 623.88 | -8.73 | -18.35 | -43.11 | -1.50 | -3.16 | -7.42 |
| | T1 | 559.71 | 532.96 | 581.47 | 620.09 | 401.69 | -21.76 | -60.38 | 71.77 | -3.89 | -10.79 |
| | T2 | 555.13 | 528.99 | 578.26 | 616.29 | 400.73 | -23.13 | -61.16 | 72.19 | -4.17 | -11.02 |
| | T3 | 550.56 | 525.67 | 574.26 | 578.41 | 399.76 | -23.70 | -27.85 | 72.61 | -4.30 | -5.06 |




4(a)




4(b)




**4 (c)**

**Fig-4 (a, b, c) Time series of estimated Water Yield of each scenario (Season wise)**

## Conclusion

In this study Arc SWAT model has been successfully explore the hydrological characteristic of basin. Proposed analysis provide valuable information on hydrological response towards climate change. As general tendency in land cover change, forest usually get converted into agriculture /Urban settlement, in such case slight increase in runoff and decrease in ET and Water yield predicted. Same trend has been found, in case of agriculture converts into urban/settlement. Also it can be concluded that increase in rainfall as well as temperature, an increasing trend identified in ET.

It is concluded that the SWAT model result in idealistic hydrology as it taken in account a large number of parameter influencing process. It was realized that to study such complex hydrological simulation between land use/ land cover and atmosphere over large area, it requires qualitative and quantitative data, in this regard; remote sensing data play an important role.

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**Conflict of Interest: None declared**

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