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# Impact on Hydrological Alteration due to Climate Change in Seti Watershed

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## ABSTRACT

This study provides streamflow and hydrologic alternation in the climate change context in Seti watershed in Nepal, which will assist planners in better managing streamflow and preparing for climate change. The Soil and Water Assessment Tool (SWAT) model was utilized in this study to simulate the hydrological dynamics of the watershed. The model has been calibrated and validated, with satisfactory performance. Future climate is projected based on the latest set of Shared Socio-economic Pathways (SSP) scenarios from CMIP6 global climate model outputs. The response of streamflow to future climate in three future periods (near, 2025-2050), (mid, 2051-2075), and (far, 2076-2100) is analyzed by comparing to a baseline. Results showed projected decrease of up to 20% during winter in both scenarios, and increase of up to 158% (SP245) and 203% (SSP585) during pre-monsoon, increase of up to 120% (SSP245) and 185% (SSP585) during monsoon, and increase of up to 103% (SSP245) and 144% (SSP585) during post-monsoon seasons.

***Keywords:*** CMIP6, Hydrology , Seti, SSPs, SWAT

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## Introduction

The constant warming of global temperatures, rapid and unplanned urbanization expansion, and land use changes have led to climate change, resulting in the increased intensity and frequency of some weather and climate extremes, particularly precipitation, droughts, tropical cyclones, and compound events (IPCC, 2022). The central Himalayan region is projected to face prolonged drought as well as food shortages in the near future (Sharma et al., 2021). (IPCC, 2022), The annual mean temperature is increasing by the 0.740 C per decade. According to the Scientific Assessment Report of the International Panel on Climate Change, by 2100 global mean temperatures will climb between 1.4oC and 5.8°C by twice as much CO2 in the atmosphere. As a result of rising global temperatures, the sea level is predicted to increase, changes in rainfall patterns, and changes in other local climates. Since 1971 to 2014, the annual maximum and minimum temperatures in Nepal climbed by 0.0560 C and 0.0020 C, respectively, while the mean annual rainfall declined by 1.333 mm per year (DHM, 2017). Understanding future climatic patterns in a particular watershed is critical for long-term water resource management. At regional scales, climate change models frequently lack precision, resulting in uncertainty in projecting local weather patterns. As a result, developing accurate and trustworthy climate projection models customized to the study area is critical. To prepare communities, policymakers, and stakeholders for future changes in temperature, precipitation, and other climatic variables that could have a substantial influence on the region's environment and water resources, this information gap must be filled. Climate change has emerged as a significant global concern, with direct implications for hydrological cycles and water resources. While the overall impact of climate change on streamflow patterns is acknowledged, there is a lack of detailed, localized studies that comprehensively assess these effects. Current research often fails to capture the nuances of how changing climate variables influence streamflow within specific watersheds. Understanding the precise alterations in streamflow dynamics due to climate change is vital for devising adaptive strategies and policies, ensuring the sustainable management of water resources in the face of evolving climatic conditions. As noted by Agrawala et al. (2003), the flows of glacier-fed rivers are anticipated to rise temporarily before declining, leading to reduced hydropower potential and increased water scarcity during critical dry periods.

The implications of these hydrological alterations extend beyond mere water availability. For instance, the frequency and intensity of extreme weather events, such as floods and landslides, are expected to increase due to climate change, further complicating water resource management (Becker & Bugmann, 1997). The combination of heavy rainfall and rapid snowmelt can lead to catastrophic flooding, impacting infrastructure, agriculture, and communities. These climate-induced disasters have already severely affected hydroelectricity generation and drinking water supplies, underscoring the urgent need for adaptive management strategies. The integration of advanced modeling techniques, such as the SWAT-MODFLOW model, has proven beneficial in understanding the interactions between surface water and groundwater in the context of climate change (Yadav et al., 2022). This integrated approach allows for a more comprehensive assessment of hydrological changes and aids in the formulation of strategies to mitigate the adverse effects of climate variability on water resources.

The impact of climate change on hydrology has been a contentious issue. There are two elements that influence the hydrological cycle, one of which is manmade and has a large impact on the water cycle. The ratio of greenhouse gas emissions is increasing as a result of several human activities (Park et al., 2011). According to (Miller & Mearns, 2002), doubling CO2 emissions globally could accelerate the hydrological cycle by 10% due to changes in evaporation and rainfall regimes. Rainfall in the southern Sahara could fall by 10% by the mid-century, resulting in water scarcity (Schnellnhuber et al., 2005). Climate change may make two-thirds of the world's population vulnerable to water scarcity (Melese, 2016). (Shrestha et al., 2016) conducted study on the Indrawati watershed in Nepal using CMIP5 models for two Representative Concentration Pathways (RCPs) scenarios and discovered that the basin's temperature has been rising, although there is no discernible increase in yearly precipitation. However, the Indrawati watershed's annual discharge is projected to rise in the future. This research aims to find out the impact on the hydrological alteration due to climate change on the Seti watershed.

Despite availability of some literature related to climate change impact on water availability, streamflow alteration, and water sufficiency at various watersheds, there are very limited studies based on application of recent shared socioeconomic pathways (SSP) scenarios from CMIP6 model outputs. Furthermore, there exists such knowledge gap in Seti watershed. This research aims to address this gap by using a model-based approach.

## Objective

The primary objective of this research paper is to investigate the impact of climate change on hydrological alterations in the Seti watershed of Nepal, with a specific focus on streamflow variability and water availability under recent Shared Socioeconomic Pathways (SSP) scenarios derived from the Coupled Model Intercomparison Project Phase 6 (CMIP6).

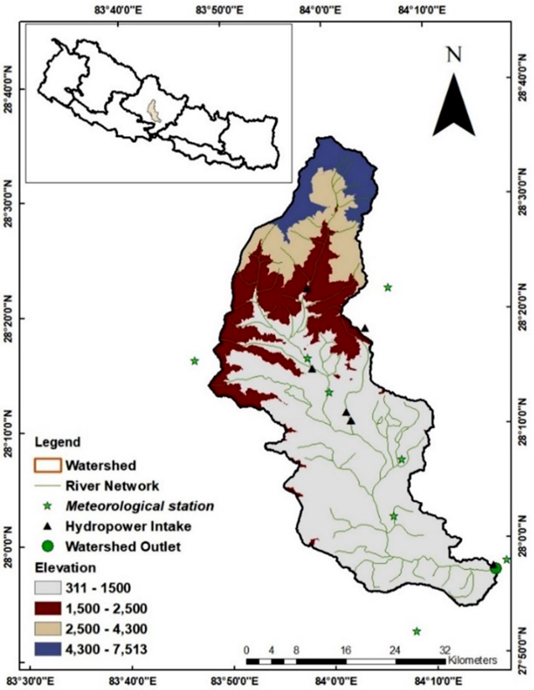
## Methodology

### Study Area

The watershed is located in Nepal's western part (province-Gandaki). It is a tributary of the Trisuli River and the Narayani River. The discharge is approximately 25 m3/sec in the winter, 26 m3/sec in the pre-monsoon, approximately 225 m3/sec in the monsoon, and approximately 70 m3/sec in the post-monsoon. Rainfall and snow melting are the two biggest contributors to river flow. The Seti watershed has a high degree of geographical variety in terrain and climate, with elevations ranging from 311 to 7513 meters above mean sea level (Figure:1).

**Figure 1**

*Detail About the Study Area*



## Data Collection

### *Historical Data*

There were 11 stations for meteorological data (eight for precipitation and four for temperature) with the time series from 1995 to 2015 which were recorded by the Department of Hydrology and Meteorology (DHM). The hydrological data for station 430.5 (Tanahun) was taken from DHM which was recorded from 2000.

**Table 1**

*Meteorological Details*

| S.N. | Station Type | Data Type | Station ID | Time Series. |
|---|---|---|---|---|
| 1. | Meteorological | Precipitation | 804, 811, 815, 817, 818, 824, 827, 830. | 1995-2015 |
| 2. | Meteorological | Temperature | 802, 804, 805, 811. | 1995-2015 |
| 3. | Hydrological | Discharge | 430.5 | 2000-2015 |

### Future Climate Dataset

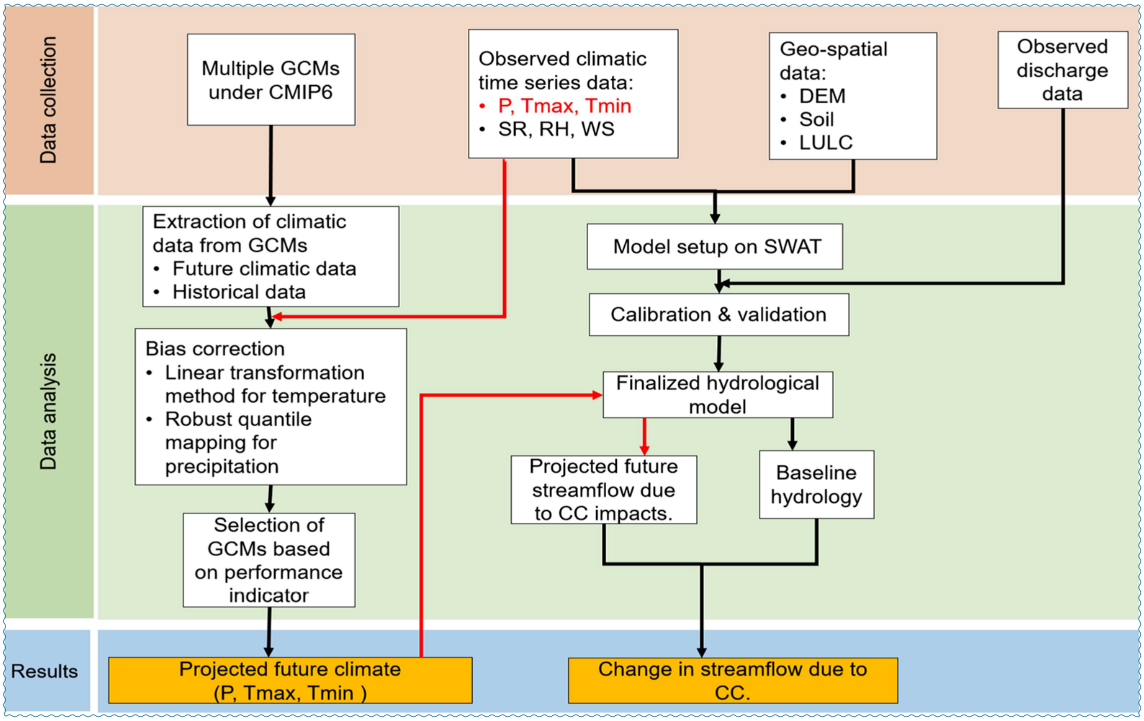
CMIP6-GCMs model outputs was collected from World Climate Research Programme Website of 0.250*0.250 resolution from (https://esgfnode.llnl.gov/search/cmip6/). Daily Precipitation and Temperature are available for these 13 GCMs. According to (Mishra et al., 2020), GCMs suitable for Nepal are NorESM2–LM, MRI–ESM2–0, INM-CM4-8, INM-CM5-0, NorESM2-MM, CanESM5, MPI-ESM1-2-LR, MPI-ESM1-2-HR, ACCESS-ESM1-5, ACCESS-CM2, EC-Earth3-Veg, EC-Earth3 and BCC–CSM2–MR.

### Methodology Chart

This study developed a hydrological model, projected future climate and assessed impacts of climate change on streamflow by applying a methodological framework as shown in (Figure:2).

**Figure 2**

*Methodology Chart of the Research*



A watershed is divided into sub-basins, which are further segmented into Hydrologic Response Units (HRUs) by SWAT. A HRU is the model's smallest unit. A stream channel connects the sub-basins. Each HRU within a sub-watershed reflects a distinct combination of soil, land use/cover, and slope type. SWAT's hydrological cycle is governed by the water balance (Arnold et al., 1998):

$$Sw_t = Sw_o + \sum_{i=1}^{n} (R_{day} - Q_{surf} - W_{seep} - Q_{gw}) \text{ .... } (1)$$

***SWt***

Soil water content at time step t, SW0: initial soil water content, Rday: daily precipitation, Qsurf: runoff, Ea: evapotranspiration, Wseep: percolation, and Qgw: groundwater flow.

In the runoff and percolation calculations, snowmelt was included alongside rainfall. In SWAT, snowmelt is a linear function of the difference between the average snow pack-maximum air temperature and the snowmelt base temperature.

$$SNOW_{melt} = b_{melt} * snow_{cov}((\frac{T_{snow} + T_{max}}{2}) - T_{melt}) \text{ .... } (2)$$

***SNOWmelt***

Daily melt factor (mm/day ℃), Tmax: daily maximum air temperature, snowcov: fraction of HRU area covered by snow, Tsnow: daily snowpack temperature (°C) and Tmelt: optimum temperature for snow melt(℃).

The Arc SWAT 2012.10.5 interface was used to create the SWAT model for the Seti watershed. The river network is generated by setting a threshold area of 500 ha. Physical characteristics of subbasins and rivers will be extracted using Arc GIS tools. 18 no. of sub-basins were generated manually during the watershed delineation which was further divided into 245 no of HRUs by defining the threshold of 10% for landuse, soil & slope. Digital Elevation Map (DEM) of grid size 30m*30m prepared by the AW3D30, Land Use Land Cover map by provided by the Integrated Mountain Development (ICIMOD) of 2010 and Soil and Terrain Database (SOTER) map of scale 1:1 million were used during the Model set up.

**Bias Correction**

Two scenarios were defined for the climate projection SSP245 and SSP585. SSP245. The selection of representative Global Climate Models (GCMS) was based on evaluating the past performance by comparing the performance of precipitation projection made by the GCMs with the baseline observed data from 1980 to 2014. For quantifying the performance, the metrics used are Nash-Sutcliffe efficiency (NSE), the ratio of root mean square error to standard deviation (RSR), and percentage bias (PBIAS). The criteria for the rating of the GCMs (Table 2)

**Table 2**

*Rating of the GCMs (D. N. Moriasi et al., 2007)*

| Performance | NSE | RSR | PBIAS | Rating |
|---|---|---|---|---|
| Very Good | 0.75<NSE<=1.00 | 0.00<RSR<=0.50 | PBIAS < 10 | 5 |
| Good | 0.65<NSE<=0.75 | 0.50<RSR<=0.60 | 10 <= PBIAS <15 | 4 |
| Satisfactory | 0.5<NSE<=0.65 | 0.60<RSR<=0.70 | 15 <= PBIAS <25 | 3 |
| Unsatisfactory | 0.4<NSE<=0.5 | 0.70<RSR<=0.80 | 25 <= PBIAS <35 | 2 |
| Poor | NSE<=0.4 | RSR>0.80 | PBIAS > 35 | 1 |

Based on the average of combined ratings of all GCMs overall selected stations, the GCMs were ranked, and the best five GCMs were selected (Table:2):

**Table 3**

*Selected GCMs for Future Projection*

| Rank | Name of GCMs | Research Centre |
|---|---|---|
| 1. | ACCESS-ESM1-5 | Australian Community Climate and Earth System Simulator (ACCESS) |
| 2. | EC-Earth3-Veg | European Community Earth (EC-Earth) |
| 3. | INM-CM5-0 | Institute for Numerical Mathematics (INM) |
| 4. | BCC-CSM2-MR | Beijing Climate Center (BCC) |
| 5. | EC-Earth3 | European Community Earth (EC-Earth) |

## Results and Discussion

### Performance of SWAT Model

The input meteorological data for the watershed were taken from the 1995-2015 and the warm-up period of three years was defined. The model was calibrated and validated using SWAT-CUP 2012 with using the parameters that are sensitive (p-value < 0.1) among 31 parameters (Table:3). And the result of the SWAT model is (Table:4):

The calibration period for this station was picked from 2000 to 2009 based on the availability of flow data, and the validation period was taken from 2010 to 2015. The hydrological model can accurately recreate the low flows, as seen by the daily and monthly hydrographs in Figures a and b. The model simulates the low flows rather well, but it slightly overestimates the big flows. based on scatter graphs of the simulated and real-world flow during the calibration and validation periods. The model can faithfully replicate the annual average flow pattern at the calibration station, according to the flow duration curve. The graph (Figure:3) and (Figure:4) represents a) Daily Hydrograph from 2000 to 2015, b) Monthly Hydrograph from 2000 to 2015, c) Flow Duration Curve, d) Cumulative Flow (Daily), e) Scatter plot of daily simulation and f) Scatter plot of monthly simulation at Tanahun Station at Station 430.5. Based on the evaluation of graphs as statistical indicators, the model performance is of acceptable level.

**Table 4**

*Sensitive Parameter Used for SWAT Model*

| Parameter Name | Fitted Value | Min range | Max range | p-value |
|---|---|---|---|---|
| R__CN2.mgt | -0.08 | -0.10 | 0.10 | 0.00 |
| V__ALPHA_BF.gw | 0.36 | 0.15 | 0.47 | 0.00 |
| V__GW_DELAY.gw | 8.75 | 0.00 | 250 | 0.00 |
| V__SURLAG.bsn | 7.31 | 0.05 | 9.97 | 0.05 |
| V__CH_N1.sub | 7.74 | 0.01 | 13.30 | 0.01 |
| V__LAT_TTIME.hru | 37.10 | 0.00 | 79.21 | 0.05 |
| R__SOL_AWC(..).sol | -0.06 | -0.10 | 0.00 | 0.06 |
| V__TIMP.bsn | 0.25 | 0.00 | 0.44 | 0.09 |

**Table 5**

*Results of the SWAT Model*

| | | Calibration (2000-2009) | Validation (2010-2015) | Entire period (2000-2015) |
|---|---|---|---|---|
| Daily | NSE | 0.68 | 0.81 | 0.71 |
| | R2 | 0.73 | 0.82 | 0.75 |
| | PBIAS | 16.3 | 10.7 | 10.7 |

**Figure 3**

*Results of SWATCUP at Tanahun Station*

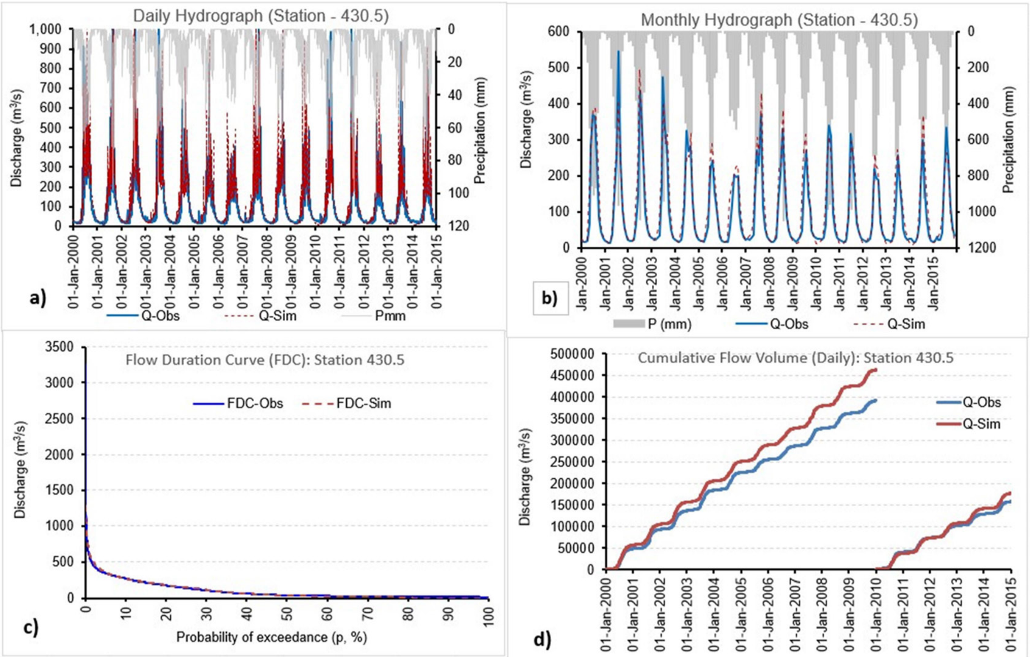
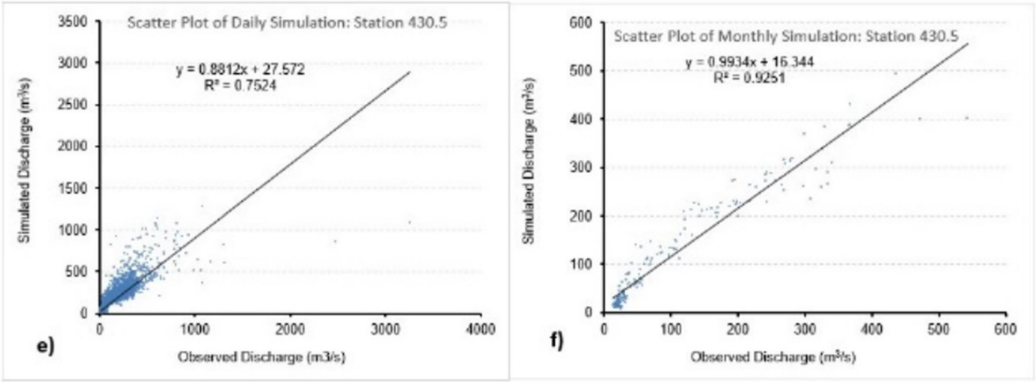


**Figure 4**

*Results of SWATCUP at Tanahun Station*

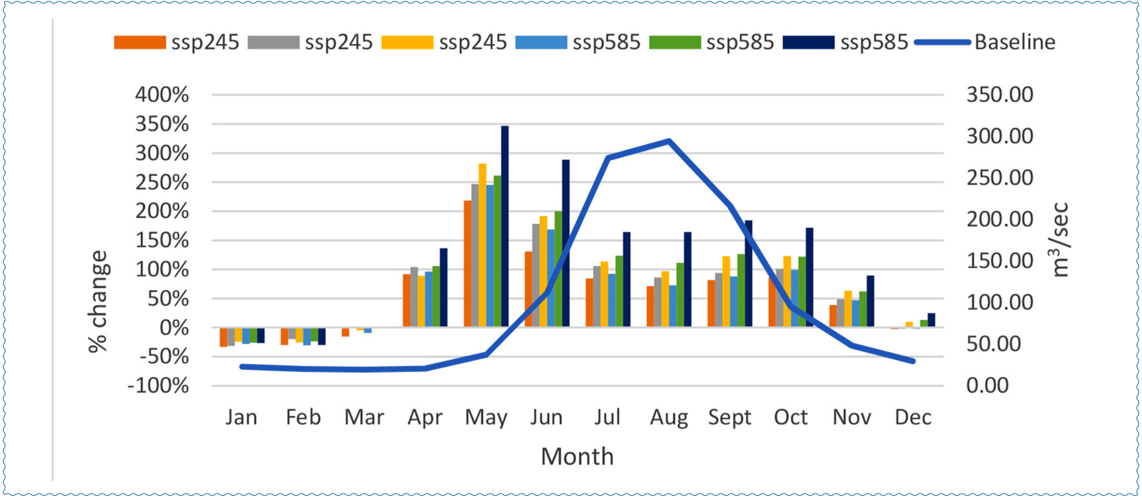


## Climate Change Impact on Streamflow

Future climate data projected for two SSPs scenario were used with the calibrated SWAT model and simulated streamflow is compared with the baseline (2000-2015). The Streamflow is projected to decrease from minimum 2% to maximum 33% during dry season and projected to increase maximum of 282% during wet season of SSP245. In SSP585 the decrease in the streamflow is projected from minimum 2% to maximum of 30% during dry season whereas, projected to increase maximum of 347% during the wet season. The future is projected to be drier during the winter season as the rate of flow in decreasing during those seasons and the pre-monsoon is projected to increase more than compare to the post monsoon. But the annual flow along every season is projected to increase in both the scenarios. According to (Dahal, M. et al., 2022), projected streamflow on the Kali Gandaki watershed on SSP245 and SSP585 shows there is slight decrease on the flow during post monsoon and increasing during the other three season with comparison to the baseline. As comparing to the Seti watershed with the baseline the flow is decreasing during the winter season but increasing during the winter, pre-monsoon, monsoon and Post monsoon season (Table:5).

**Figure 5**

*Future Streamflow at Seti Outlet*



The baseline is plotted and the its monthly alteration with respect to the baseline is compared within the percentage and result is plotted in the graph. The figure shows the different projected alteration on SSP245 and SSP585 (Figure 5).

**Table 6**

*Projected change (%) in Streamflow w.r.t. Baseline at Outlet of Seti Watershed*

| Months | Baseline | ssp245 | | | ssp585 | | |
|---|---|---|---|---|---|---|---|
| | | | MF | FF | NF | MF | FF |
| January | 23.10 | -33% | -32% | -24% | -28% | -26% | -26% |
| February | 20.37 | -30% | -20% | -25% | -30% | -24% | -30% |
| March | 19.53 | -16% | 1% | -5% | -10% | 0% | -1% |
| April | 20.50 | 92% | 104% | 89% | 96% | 105% | 136% |
| May | 37.42 | 218% | 247% | 282% | 245% | 261% | 347% |
| June | 111.89 | 131% | 178% | 192% | 169% | 200% | 289% |
| July | 274.09 | 84% | 105% | 113% | 92% | 123% | 164% |
| August | 294.46 | 71% | 86% | 97% | 73% | 111% | 164% |
| September | 216.70 | 81% | 94% | 122% | 88% | 126% | 184% |
| October | 95.10 | 86% | 101% | 123% | 99% | 122% | 172% |
| November | 48.26 | 39% | 49% | 63% | 47% | 62% | 90% |
| December | 29.65 | -2% | -2% | 10% | -2% | 13% | 25% |

**Table 7**

*Projected change (%) in Streamflow w.r.t. Baseline at Outlet of Seti Watershed*

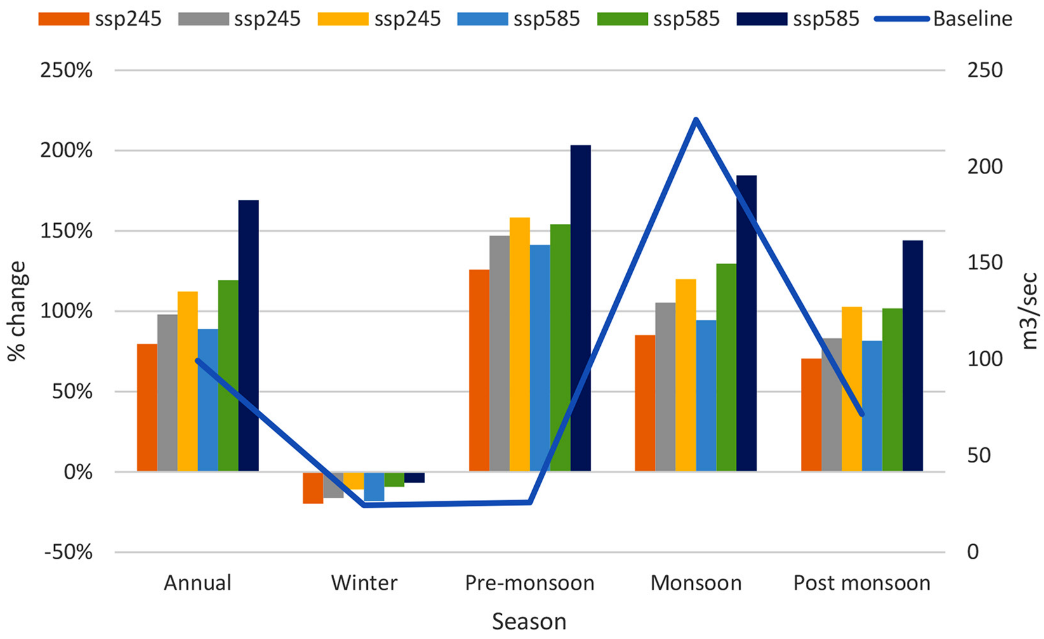
| Period | BL(m3/ sec) | ssp245 | | | ssp585 | | |
|---|---|---|---|---|---|---|---|
| | | NF | MF | FF | NF | MF | FF |
| Annual | 99.25 | 80% | 98% | 112% | 89% | 119% | 169% |
| Winter | 24.37 | -20% | -16% | -11% | -18% | -9% | -7% |
| Pre-monsoon | 25.81 | 126% | 147% | 158% | 141% | 154% | 203% |
| Monsoon | 224.28 | 85% | 105% | 120% | 94% | 130% | 185% |
| Post Monsoon | 71.68 | 70% | 83% | 103% | 82% | 102% | 144% |

According to Shrestha et al.,( 2016), the annual streamflow of the Indrawati watershed is projected to increase in the future. So, comparing the result of the Seti watershed shows the same increasing trend in the future. The result of the outlet is further defined with the annual and seasonal flow with both the scenarios SSP245 and SSP585 are tabulated and plotted in graph.

The baseline is plotted and the its annual and seasonal alteration with respect to the baseline is compared within the percentage and result is plotted in the graph. The figure shows the different projected alteration on SSP245 and SSP585 (Figure 6).

**Figure 6**

*Seasonal Alteration at Watershed Outlet*



## Conclusion

The projected changes in streamflow across the Seti watershed present both challenges and opportunities for water resource management in Nepal. As the study indicates, streamflow is expected to increase during the pre-monsoon, monsoon, and post-monsoon seasons, while a significant decrease is anticipated during the winter months. Specifically, the forecast suggests that winter streamflow could reduce by up to 30%, indicating a trend towards drier winters. Conversely, the monsoon season is projected to become wetter, with streamflow increases of up to 282% under the SSP245 scenario and up to 347% under the SSP585 scenario. These shifts highlight the need for adaptive management strategies to address the changing hydrological patterns.

The implications of these changes are profound, particularly for hydropower generation and irrigation projects. The anticipated increase in streamflow during the wet seasons will enhance water availability for hydropower projects, potentially leading to increased energy production during the dry season. This is particularly critical for Nepal, where hydropower is a key component of the national energy strategy. By capitalizing on the increased water flow during the monsoon, hydropower facilities can optimize their output, thereby contributing to energy security and economic growth.

Moreover, irrigation projects stand to benefit significantly from the projected increases in dry season water supply. Improved water availability can enhance agricultural productivity, supporting food security and livelihoods for rural communities. This is especially important in a country like Nepal, where agriculture is the backbone of the economy and a primary source of income for a large portion of the population.

However, these opportunities must be approached with caution. The projected increases in streamflow also pose risks, such as potential flooding during the monsoon season, which could have devastating impacts on infrastructure, agriculture, and communities. Therefore, it is essential to develop comprehensive water management strategies that not only harness the benefits of increased streamflow but also mitigate the associated risks. This includes investing in flood management infrastructure, enhancing early warning systems, and implementing sustainable land-use practices to reduce runoff and erosion.

Furthermore, the findings underscore the importance of stakeholder engagement in water resource management. Collaborative efforts among government agencies, local communities, and private sector stakeholders are crucial for developing effective strategies that address the diverse needs and challenges of water management in the context of climate change. By fostering a participatory approach, stakeholders can ensure that water management practices are equitable, sustainable, and resilient to future changes.

The projected changes in streamflow within the Seti watershed present both significant opportunities and challenges for Nepal. By proactively addressing the implications of these changes through adaptive management strategies, stakeholder collaboration, and investment in infrastructure, Nepal can enhance its resilience to climate variability while maximizing the benefits of its water resources. This holistic approach will not only support the country's hydropower and agricultural sectors but also contribute to the overall socio-economic development and environmental sustainability of the region.

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