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Seasonal Variation in Budhni Nullah's Flows Under Changing Climate

Sajadullah[1*], Dr. Asif Khan[2], Naila Ahmed[3]
[1]Directorate of Agricultural Engineering Department Khyber Pakhtunkhwa Tarnab, Peshawar, Pakistan
[2]Faculty of Civil Engineering, University of Engineering and Technology Peshawar, Pakistan
[3]Research Scholar Bahria Univerity Islamabad
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***Abstract*—**Climate Change, an inevitable phenomenon, is impacting weather patterns and causes extreme climatic events. Pakistan is the 5th most affected country by climate change world wide. Globally, Pakistan is highly susceptible to temperature rise, due to its geographic location. This study explores the effects of climate change on the seasonal flows of Budhni Nullah. In order to investigate the effect of changing climate, bias-corrected data of five General Circulation Models (GCMs) of "Coupled Intercomparision Project-6" (CMIP6), under Shared Socioeconomic Pathway (SSP2-4.5) have been used. The hydrologic model, Soil and water assessment Tool (SWAT) was calibrated and Validated for a period of six years (2002-2008) and four years (2009-2013) respectively with statistical functions: R-squared, 0.78 & 0.58, Nash–Sutcliffe efficiency, 0.75 & 0.80. Three future time periods: (2011-2040), (2041-2070) and (2071-2100) of each 30 years were selected and accordingly. The average monthly flow was modeled for SSP245. Comparison of the results reveal that, for majority of the time, an increase in flows were witnessed during the monsoon season. Higher flows were observed during the time period of 2011-2040.

Keywords— Climate Change, CMIP6, SSP2-4.5, SWAT.

I. Introduction

Climate change, an inevitable phenomenon, is a threat to the survival of mankind. It is defined as long-term alteration in properties of climatic systems, as a result of natural or forced variability and anthropogenic activities. The effect of climate change on hydrology is crucial, as climatic systems and hydrological cycle are physically likened [1] Moreover, as per report of American Meteorological Society, there is more than 90% chance that temperature will increase around 3.5 to 7.4°C in a period, less than one century, globally.

In Pakistan, climate change has caused severe climatic events: starting from heavy rainfalls; unexpected floods; life-threating droughts; and elevated sea-level to rapid pace glacier melting. Similarly, German watch ranked Pakistan at number 8th in the list of countries highly vulnerable to climate change [2]. Asian Development Bank (ADB) says, annually, Pakistan suffers a financial loss of 3.66 billion US dollars, due to the menace of climate change[3]. Furthermore, in the last five decades the annual average temperature has increased by 0.5 °C. For a central global emission scenario, a rise of 3ºC to 5ºC in the average annual temperature in Pakistan is predicted till the last period of this century. However, an increase of 4 °C to 6 °C is projected under a higher global emission scenario [4]. Moreover, changing precipitation patterns and warmer climates are also predicted, which will significantly impact flows in rivers in the region of Hindu-Kush Karakoram Himalaya (HKH), including the basin of the Kabul River [5]. Moving to the end of the 21st century, HKH region's average surface temperature will rise. It is projected that the temperature, will be higher in the region than the mean surface temperature globally due to its geographic location [6]. This temperature rise in the region, would cause significant changes in climate trends and the water cycle [7]. Similarly, for a 1°C rise in average temperature in UIB, there will be 16-17% increase in runoff [8], which demonstrates the sensitivity of UIB's water resources to changing climate.

A recent study shows a warming scenario, using SWAT for five GCMs data, under RCP4.5 and RCP8.5, with expected high precipitation in UIB. It shows that climate change threatens water resources enormously. The temperature is rising, leading to temporal and spatial shifts in rainfall patterns and changes in the timing of snowfall and melting of glaciers. These factors are major reasons for shifting seasonal flows in rivers.

Similarly, as per findings of Special Reports on Emission Scenarios (SRES) on Upper Northern region of Pakistan having latitude > 35° N, a significant rise in winter precipitation, 10% as compared to base period, is expected in the winter season. This forecast is substantiated by 2/3rd of the model results, regardless of the forecast period and emission scenario [9].

Geographically, Pakistan is more susceptible to temperature rise compared to the global average, due to its location. On the top of that, there is huge diversity in precipitation and temperature with dry and cold areas. The north experiences pleasant winters and scorching, dry summers, while the west and south have semi-arid and arid regions [10].

GCMs are thought to be straightforward and efficient ways to monitor climate change. CMIP program objectives include: adequate evaluation of past, current, and projected climate variability. The sixth edition (CMIP6), a project of World Climate Research Programme, provides latest hydro-climatic data, which has not only escorted a new age for climate science, but has also grown to be a crucial component of climate change assessments [11] . Downscaled bais corrected climatic data of CMIP6 was used for calibration, validation and future projection using Soil and Water Assessment Tool (SWAT). SWAT is used to project runoff, sediment and nutrient transport in cultivable basins and erosion under various management techniques [12].

Due to the perpetual threat of variation in seasonal flow of Budhni Nullah and its impact on down-stream localities, it cannot be overlooked. It is important to predict possible future's flows under changing climate and propose sustainable solutions. However, studies have been conducted in the Budhni Nullah for seasonal variation in flow and precipitation. Five General Circulation Models of CMIP6 have been used under SSP245, to establish a relation between seasonal flow and climate change.

II. Material and Method

A. *Study Area*

In this research, Budhni Nullah was selected for seasonal variation in flows which is located in East of district Peshawar having coordinates between 33.878° to 34.3533° N and 71.491°to 70° E. Also, the length of Nullah is 24.56 km and it is having catchment area of approximately 77,753 ha. Besides this, the topography of the catchment area consist of plains and mountainous areas; and predominantly the soil texture is Loam and Clay-Loam.

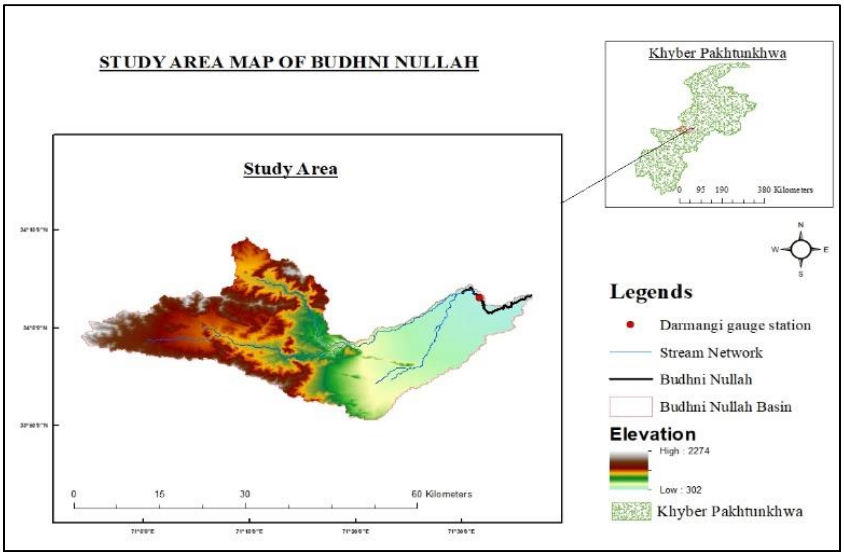


Figure 1. Location map of study area

Data used in this study

Spatial and temporal data of watershed were collected. Spatial data consists of DEM (SRTM 30x30m resolution), LULC (ESRI, 2021, 10x10m resolution) and soil data which was downloaded from United States Geological Survey department (https://earthexplorer.usgs.gov/) / FAO, 30x30m resolution. Temporal data consists of flow and climatic data. Moreover, after collection of data the spatial and climatic data were converted into projected coordinate system and tab delimited (*.txt) respectively.

Development of SWAT Model

Researchers describe SWAT as extremely productive in impact assessment investigation in vast watershed. It is very effective at forecasting future flows (monthly, seasonal, and annual) and works quite effectively in Snow melt runoff (SRM) studies [12]. For development of SWAT model, DEM file was incorporated into SWAT. After successful incorporation, the watershed delineation, LULC and soil data were also incorporated. As a result, eleven sub basin were formed.

Sensitivity Analysis

For identification of sensitive parameters sensitivity analysis Sequential Uncertainty Fitting-2 (SUFI-2) was used.

Calibration and Validation

In this stage, the observed and modeled Parameters were compared under same condition. After successful calibration, the same procedure was used for validation. To remove ambiguity from model simulation calibration of model is essential step.

III. Result And Discussion

Calibration and Validation

Model performance and validity are evaluated through statistical functions. Generally three statistical function are used to check performance of model i.e. NSE, RSR and PBIAS. For stream flow it is considered satisfactory if NSE > 0.50, RSR < 0.70 and PBIAS ± 25%.

Under the same parameters the model was calibrated for a time period of 6 years (2002-08) and afterward validated for 4 years (2009-13) as shown in "Fig. 2".

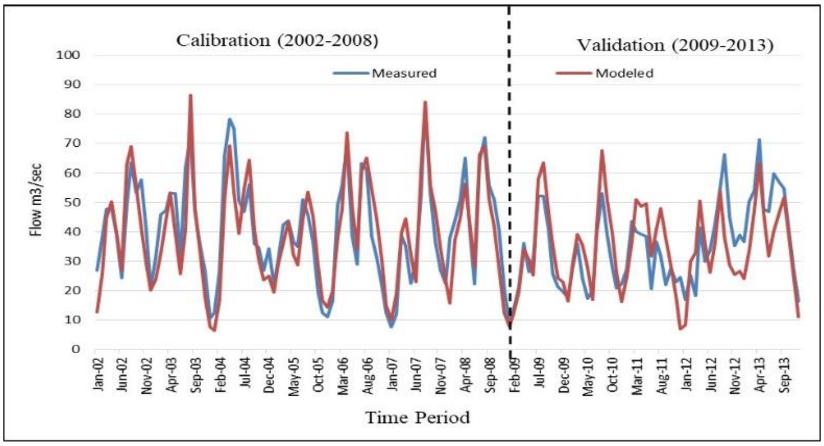


Figure 2. Calibration & Validation of Model

From the above figure it is evaluated that the calibration and validation performance of model come under the satisfactory category.

Monthly average flow comparison under SSP245

Thirty years data of monthly average flow is compared in Table1.

Table 1. Monthly Average flow Comapision (SSP245)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1981-2010	3.9	8.4	16.2	20.7	16.0	9.9	15.5	21.1	18.1	13.0	7.8
2011-2040	4.0	10.2	18.4	21.8	16.6	12.0	20.6	25.2	20.5	14.1	7.5
2041-2070	4.9	10.2	15.6	17.7	12.8	9.5	22.7	28.5	21.5	13.6	7.5
2071-2100	3.9	9.7	17.0	17.2	12.2	11.8	19.8	26.8	20.6	13.9	7.7

It is evalauted that overall increase occur in flows mostly in Monsoon period (July-Sep), with 22% rise, excluding the month of October and December where the flow decreased by 3% and 19% respectively with respect to base period for time period followed by base period. However, for the next two consecutive time slices (2041-70 & 2071-2100) a significant decrease in flows can be seen in months of April (14%, 17%) and May (20%, 24%) respectively, while paramount increase of 33% and 23% were observed in monsoon period as compare to base period for the mentioned time period respectively. This increase in monsoon period is a result of high precipitation as shown in "Fig. 3".

Average Seasonal flow comparison under SSP245

Flows under SSP245 was produced to check the variability in different seasons. Table 2 shows average flow in two crop season i.e., Rabi and Kharif. Similarly, table 3 show comparison in percentage in future time periods with respect to base period, and finally the "Fig. 3" not show graphical representation, but also show the relation of seasonal precipitation with flow.

Table 2: Comparison of average seasonal flows under SSP2-4.5

S. No	Period	1981-10	2011-40	2041-70	2071-2100
1	Annual	12.9	14.3	14.1	13.8
2	Rabi	8.9	9.5	9.4	9.8
3	Kharif	16.9	19.1	18.7	17.7

Table 3: Comparison of average seasonal flows under SSP2-4.5 percent

S. No	Period	Precipitation (mm)	Tmax	Tmin
		SSP245	SSP245	SSP245
1	2011-2040	-0.16%	0.02%	0.13%

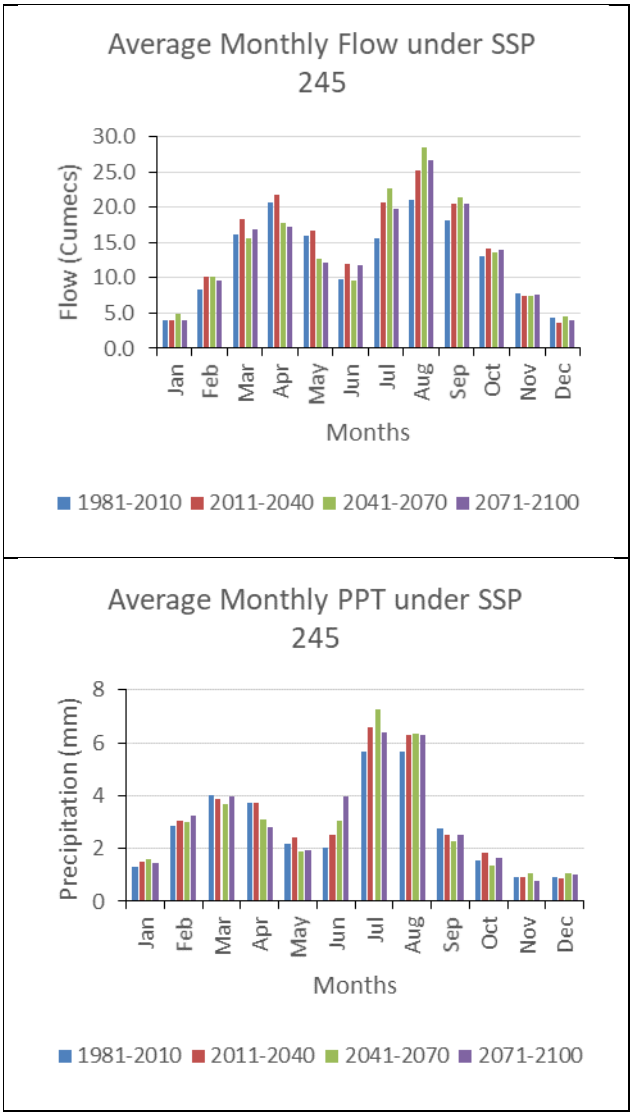
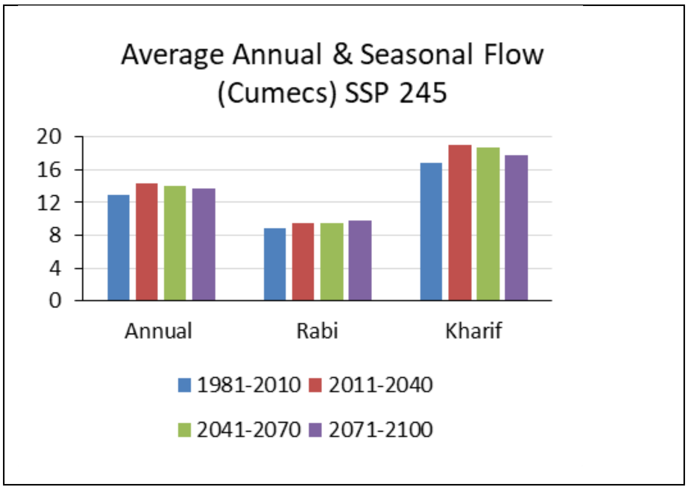


Figure 3. Monthly average flow and PPT(SSP245)



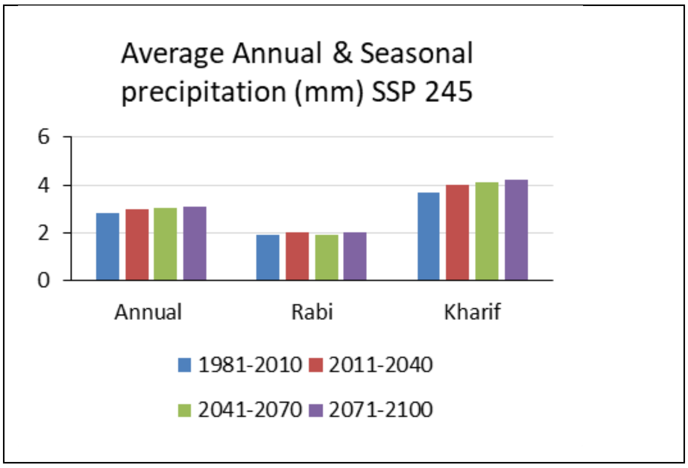


Figure 4 . Average annual and seasonal flow

Seasonal Flows and PrecipitationVariations are compared in detail in Fig 4. It projects an increase in the flow in Kharif Season and decrease in Rabi Season. The increase is 47%, 51%, 50% & 48% as compare to Rabi season for four time slices each of 30 years under SSP245. The Increase in Kharif Season's flow is the result of high precipitation, because of monsoon season.

CONCLUSION

It is concluded that the model simulation falls in the category of satisfactory as NSE & R2 > 0.50. Under SSP245, increase in flows, particularly in Monsoon period (July-Sep), with 22%, 33% and 23% were observed in future time periods with respect to base period. However, a significant decrease in flows in months of April (14%, 17%) and May (20%, 24%) were observed in last two future time slices. Moreover, seasonal flow variation comparison projects an increase of 47%, 51%, 50% & 48% in Kharif season as compare to Rabi season for four time slices each of 30 years under SSP245.

NOTATIONS

NSE = Nash-Sutcliffe efficiency
RSR = ratio of the root mean square error to the standard deviation of measured data
PBIAS = percent bias
R^2 = Coefficient of determination
DEM = Digital Elevation Model
GCM = General Circulation Models
HEC-RAS = Hydrologic Engineering Centers River Analysis Sys
CMIP6 = Coupled Intercomparision Project-6
LULC = Land Use Land Cover
RCP = Representative Concentration Pathways
SWAT = Soil and water assessment Tool
SSP = Shared Socioeconomic Pathways
KP= Khyber Pakhtunkhwa

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Engr. Sajadullah[1*], Upper Dir, KP, Pakistan and D.O.B: 08/04/1991
Agricultural Engineer, Directorate of Agricultural Engineering Department, KPK, Tarnab, Peshawar, Pakistan.

Dr. Asif Khan[2], Peshawar, KP, Pakistan
Faculty of Civil Engineering, University of Engineering & Technology Peshawar, Pakistan

Naila Ahmed[3], Rawalpindi, Punjab, Pakistan
Research Scholar Bahria University Islamabad

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