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The Impact of Climate Change on the Basin Hydrology using CMIP6 Data: A Case Study of Kankai Basin

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Abstract

Climate change is one of burning and day to day life facing problem which effects on various dimensions like hydropower, irrigation, water supply, domestic and industrial aspect of mankind. The planning and management of water resources is a major problem throughout the globe. The current study is focused with the objective of impact of climate change on the water balance components of Kankai basin of Eastern Nepal.Kankai Basin is located in eastern part of Nepal. The catchment area of the Kankai basin is 1165 square kilometer. The Soil and Water Assessment Tool (SWAT) was applied for the analysis of water balance components of the basin. The calibration and validation results show very good accuracy instead of having issue in the accuracy of observed data obtained from DHM. The downscaling and bias correction of CMIP6 data with statistical downscaling CMHYD under the SSPs 245 and 585. The projected climate change data from 13 GCMs were averaged and forced into the model for climate change impact analysis from 2021 to 2100. The basin is divided into upper and lower reach having 6 sub basins. The water balance components like evapotranspiration, ground water discharge, surface discharge etc. were analyzed in all sub basins from the 2021 to 2100 under SSPs 245 and 585. There will be rise in almost all the components of water balance which will be boon from agriculture and irrigation point of views. To avoid harm and loss of life, property due to flood and drought condition, making proper preparation and planning in advance is needed.

Keywords

Water balance components, Climate change, SWAT, Kanakai basin

1. Introduction

A watershed model is representation of various water related phenomenon in simplified conceptual form. Watershed modeling helps in decision making among water sector with river basin approach. Result obtained from SWAT model shows variation of precipitation, water available, and evapotranspiration within basin. There is large variation in water balance components. A semi distributed hydrologic model soil and water assessment tool (SWAT) is used to simulate single or multiple hydrological connected watershed. Watershed is divided into sub-basin and then into HRU (hydrologic response units) depending upon land use and soil type. A water budget is calculated for each HRU based on surface runoff, ground water, lateral flow, soil moisture, evapotranspiration etc [1].

Climate change effects basin hydrology by affecting water availability and quantity which makes climate change as a topic of interest to meteorologist and scientists to quantify climate change impact on stream flow as regional and basin scale. Estimation of climate change helps to reduce negative impacts as well as increase water security for management. Climate change is uncertain due to climate models, downscaling and bias correction method used in the process. Thus use of various climatic model is best way to minimize uncertainties in the process. The use of SWAT is very commonly seen in simulation of basin hydrology under different climatic scenarios [2].

Water balance components are surface runoff, ground water flow, precipitation, soil water availability, evapotranspiration. There are several components in water balance which makes difficult or challenging task for quantification of various components of water balance. The water balance components can be realistically simulated using various watershed hydrologic model. There is question how the water balance components vary in relation to climate change [3].

Climate change effects enormous challenge on the water resources, agriculture, infrastructure and livelihood of millions of people in South Asia. South Asia is globally hot spotted which faces severe climate change impact. Precipitation and temperature has increased considerably in past decades and will rise further under warming climate. GCMs plays important role in projecting future climate change. However, spatial resolution to which GCMs are run often too coarse to get reliable projection at regional and local scale. Bias correction is required. [4].

Climate change effects basin hydrology in various ways as hydrological cycle completes with temperature and radiation which influences life of human being, their way of living and economy. Climate change effects components of basin hydrology (eg. Precipitation, evapotranspiration, runoff, ground water, snow melt etc.) Such changes in these components effect every aspect of human being from agricultural, energy used to flood control, water supply, hydropower etc [5].

In this study, a methodology has been proposed for estimating the effects of climate change on the basin hydrology of a watershed using a hydrological model (SWAT), coupled with a future climate change scenario predicted by Global Circulation model (CMIP6). SWAT is one of the most widely-used watershed-scale simulation tools used around the world to address watershed questions and is capable of predicting the effect of soil, land use, and management on water. The efficiency of this model was found to be well fitted in many basins of Nepal [6].

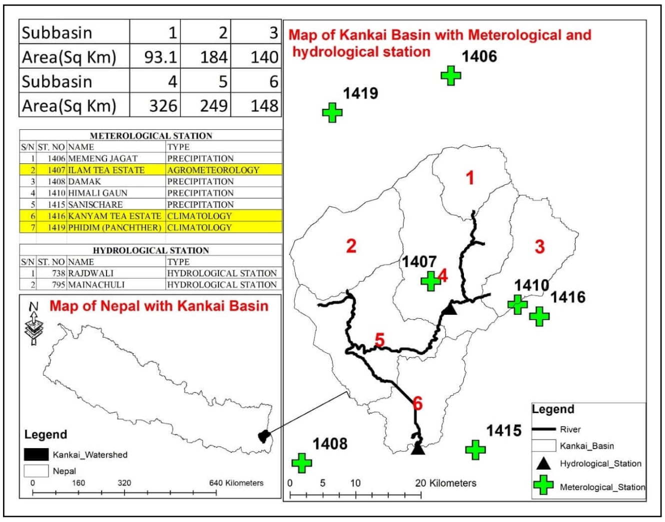
1.1 Objectives of the study

Following are the general and specific objectives of the study.

- To study the impact of climate change on the water balance of Kankai basin under two scenarios (SSP 245 and SSP 585).
- Comparison of water balance components of sub basins.
- To study the spatial and temporal rainfall within the basin under two scenarios.

2. Study Area

The Kankai basin of Eastern Nepal is selected as the study area.



Subbasin	1	2	3
Area(Sq Km)	93.1	184	140
Subbasin	4	5	6
Area(Sq Km)	326	249	148

METEROLOGICAL STATION

S/N	ST. NO	NAME	TYPE
1	1406	MEMENG JAGAT	PRECIPITATION
2	1407	ILAM TEA ESTATE	AGROMETEOROLOGY
3	1408	DAMAK	PRECIPITATION
4	1410	HIMALI GAUN	PRECIPITATION
5	1415	SANISCHARE	PRECIPITATION
6	1416	KANYAM TEA ESTATE	CLIMATOLOGY
7	1419	PHIDIM (PANCHTHER)	CLIMATOLOGY

HYDROLOGICAL STATION

S/N	ST. NO	NAME	TYPE
1	738	RAJDWALI	HYDROLOGICAL STATION
2	795	MAINACHULI	HYDROLOGICAL STATION

Figure 1: Study Area

Kankai Basin is located in eastern part of Nepal. The latitude and longitude for the selected study area lies between 26°41′ to 27°07′N and 87°44′ to 88°09′E respectively.The catchment area of the Kankai basin is 1165 square kilometer. The elevation of the catchment area varies from 130 m to 3535 m above mean sea Level [7]. The basin is divided into upper and lower reach. The basin is again sub divided into six sub basins having area shown in the table in study area. There is 7 meteorological station and 2 hydrological stations located close to basin. The land use pattern within the catchment can be classified into agricultural land, natural forest, scrub land, urbanized area etc. The agriculture land consists of terrace type land. The crops grown in agricultural lands are paddy, wheat, maize, potato, ginger, millet, cardamom, vegetables etc. The forest and scrub lands are natural and maintained by community as community forests.

3. Materials and Methods

3.1 Remote sensing data

Table 1: Basic information about the data used in Kankai basin

Data	Date	Spat. resol	Source
SRTM DEM	2014	30	USGS
hwsd soil map	2008	900	FAO
Rainfall and temp. data	2007-2019		DHM
LULC	2015		ICIMOD
Discharge	2007-2019		DHM

3.2 DEM

DEM (Digital Elevation Model) represents the topographical features of the study area. The DEM used in this analysis is 30m resolution downloaded from the open sources USGS. The required shape of DEM is clipped using Arc GIS tool for the analysis of watershed delineation, stream and river flow path.

3.3 Land use and Land cover

The land use and land cover map 2015 having grid size 30*30 for the basin was downloaded from the ICIMOD. The maps were also available for more recent years but were not providing more clear view as required for our study. LULC map is categorized into 8 classes as forest, grass land, barren land, agricultural land, water body, bush etc. the basin is dominated by agricultural land.

3.4 Soil map

The soil cover map is Kankai basin was clipped from Harmonized World Soil Database (HWSD) prepared by FAO. Soil layer for basin is categorized into two major classes.

3.5 Meteorological station of Kankai basin

Climate data includes precipitation, temperature data. For the Kankai basin data were obtained from the Department of Hydrology and Meteorology (DHM), Government of Nepal. Temperature and humidity data were obtained from climatology. Discharge was taken from Hydrological station.

3.6 Soil, land cover map and DEM map of the basin

Soil map HWSD (Harmonized world soil data) developed by FAO is downloaded and clipped for the basin having two types of classification. DEM (digital elevation model) data shows that Kankai basin having higher value of 3476m and lower value of 118 m above the sea level. The land use land cover map has divided the basin into eight sub classes forest, grass land, water body, urban, agricultural land etc.

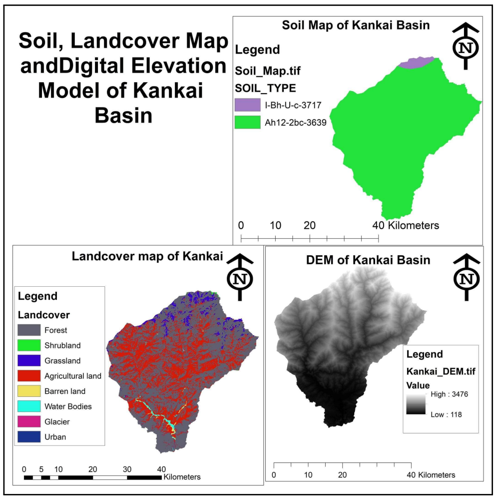


Figure 2: Soil, land cover map and DEM

3.7 Research Design

The frame work of the research design can be seen below. This research tends to find the impact of climate change in basin hydrology of Kankai basin. The procedure for the research are as follows:

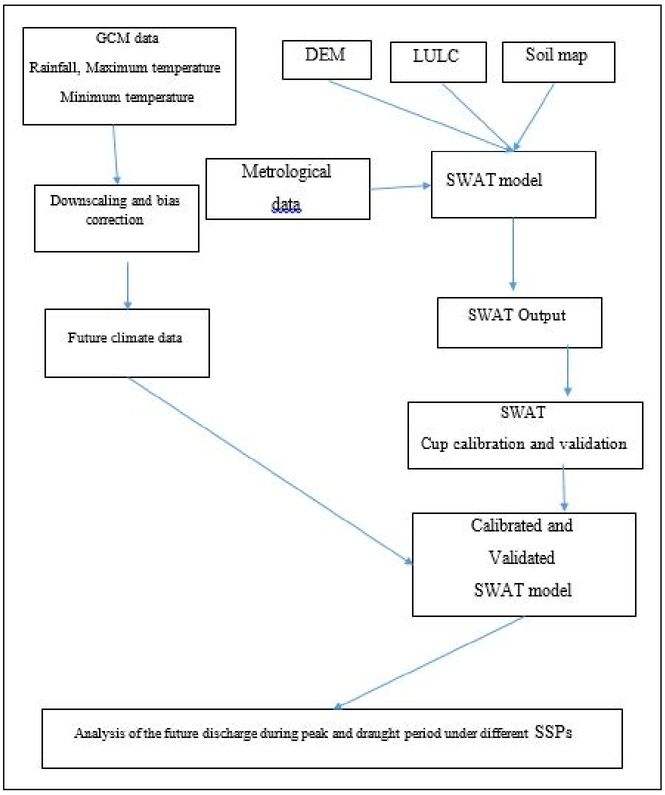


Figure 3: Frame work of research design.

The GCM data will be downloaded from the CMIP6 (Couple Model inter-comparison project) data. It will be downscaled from GCM to RCM and bias corrected. The data will be prepared in the SWAT format. The SWAT model will be set up for Kankai basin, the calibration and validation will be done for 5 years and the sensitive parameters were identified. With the GCM data the impact of climate change in basin hydrology can be determined. The analysis will be done based on the SWAT output. The SWAT output will be analyzed based on the flow duration curve for each scenario (SSP245 and SSP585), discharge under dry period (November-April) will be determined, rainfall distribution for the decade 2021-2040, 2041-2060, 2061-2080 and 2081-2100

3.8 Bias correction

CMhyd tool has been used for bias correction which effectively supports spatial as well as temporal bias correction of data obtained from climatic model. We have used 13 climatic models in our study. The observed data has higher spatial correlation with CMIP6 model comparing to CMIP5 GCMs. Other indicators like RMS error, SD etc. have better performance and control with CMIP6.

4. Results and Discussion

4.1 Calibration Results

The fig. below is the graph comparing the observed flow to the simulated flow for the calibrated year of 2010 to 2014. The hydrograph shows the comparison of observed flow with simulated flow during calibration. The dotted line show observed outflow and solid line show simulated outflow at that junction, and downward cluster graph indicate the monthly precipitation.

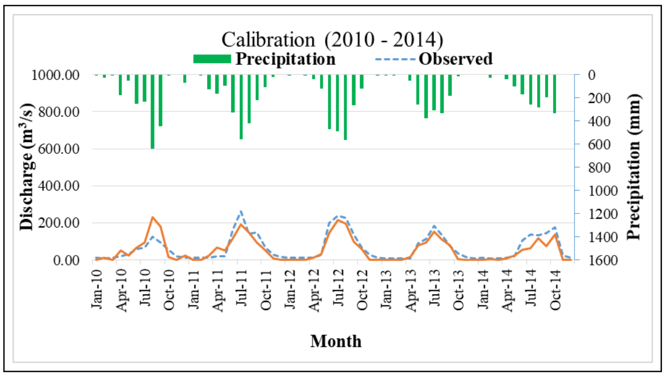


Figure 4: Calibration of Hydrograph.

Automatic calibration techniques were applied to estimate values of parameters. After calibration total simulated outflow volume was found to be almost equal to the total observed volume. The NSE for calibration period was 0.77 which indicate that NSE value, R2, PBIS and RSR of the calibration after the 18 iteration are shown above on the table. Simulated values are very good fitted to hydrograph as performance classification of Moriasi [8]. Similarly the other indicators have also good correlation with observed data.

Table 2: Table for the results of indicator of calibration

SN	Indicator	Calibration result
1	R-square	0.80
2	NSE	0.77
3	PBIAS	16.9
4	RSR	0.48

4.2 Validation Results

The parameters within the calibration period were kept same and model was run for the year of 2015 to 2019 up to 5 years for the validation.Statically, the result of the validation period are better than the calibration period. The NSE value 0.78, R2 values 0.85 which indicates model has very good performance as per the performance classification of Moriasi.

Table 3: Table for the results of indicator of validation

SN	Indicators	validation results
1	R-square	0.85
2	NSE	0.78
3	PBIAS	29.3
4	RSR	0.45

4.3 Sensitivity parameters

The figure in the bar graph shows the SWAT parameters with values indicated which is most sensitive. It indicates Kankai basin has major contribution of ground water source than other. Ground water is one of major dominating parameters of the basin among 9 sensitive parameters 6 are groundwater dominating parameters.

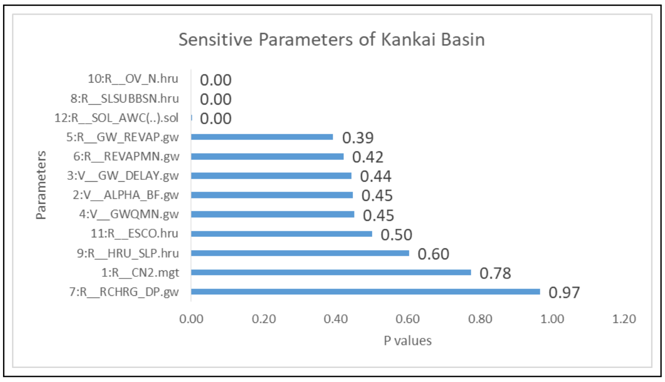


Figure 5: Sensitive P value parameters during calibration.

4.4 Temporal variation of water balance components in each sub basin under two scenarios of SSP 245 and SSP 585 from 2021 to 2100

In the future projection from 2021 to 2040, evapotranspiration is higher in the sub basin one, ground water contribution is higher at the sub basin six and surface discharge is higher at the sub basin two under both the SSP 245 and 585.

In the future projection from 2041 to 2060, evapotranspiration is higher in the sub basin one, ground water contribution is higher at the sub basin two and surface discharge is higher at the sub basin six under both the SSPs 245 and 585.

In the future projection from 2061 to 2080, evapotranspiration is higher in the sub basin two under SSP 585 and under SSP 245 it is higher at sub basin one. Ground water contribution is higher at the sub basin two under both the SSPs. Surface discharge is higher at the sub basin six under both SSP 245 and 585.

In the future projection from 2081 to 2100, evapotranspiration is higher in the sub basin one. Ground water contribution is higher at the sub basin six under SSP 585 and under SSP 245 it is higher

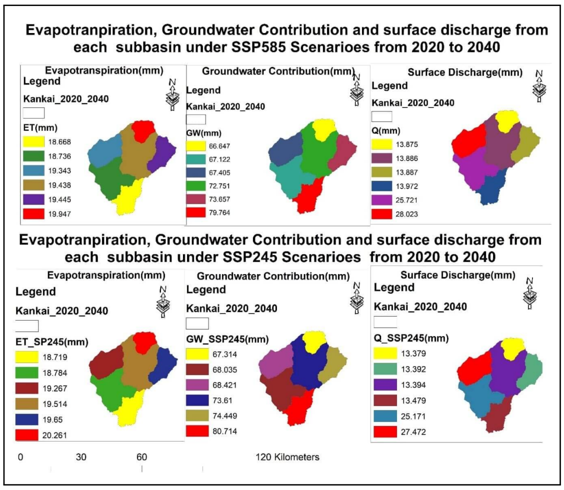


Figure 6: Evapo-transpiration, ground water and discharge components in each sub basin SSP 245 and 585 from 2021 to 2040

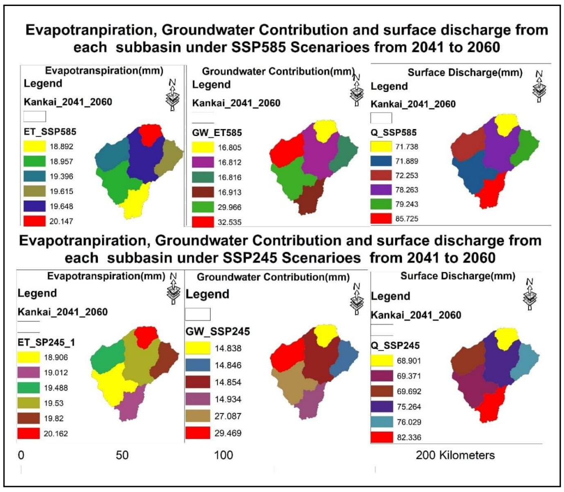


Figure 7: Evapo-transpiration, ground water and discharge components in each sub basin SSP 245 and 585 from 2041 to 2060

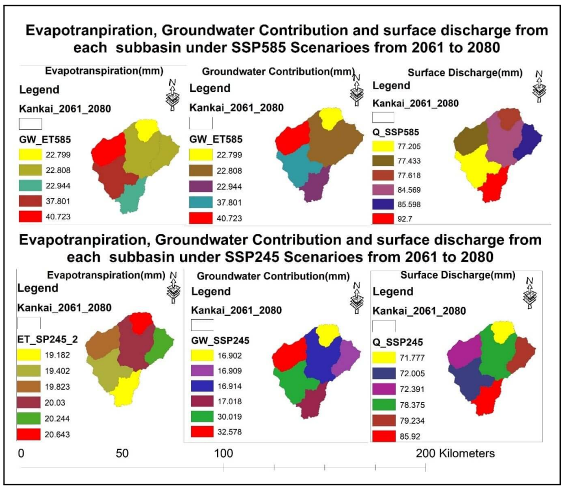


Figure 8: Evapo-transpiration, ground water and discharge components in each sub basin SSP 245 and 585 from 2061 to 2080

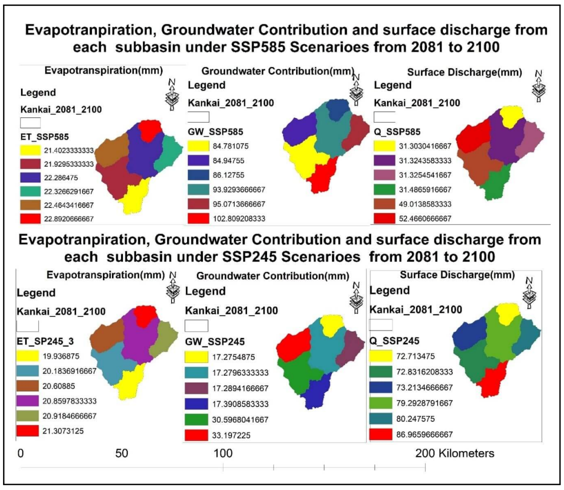


Figure 9: Evapo-transpiration, ground water and discharge components in each sub basin SSP 245 and 585 from 2081 to 2100

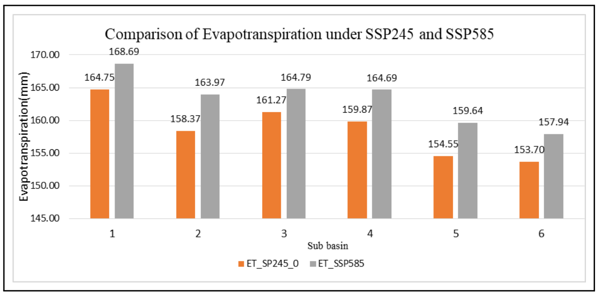


Figure 10: Comparison of evapo-transpiration in each sub basin under SSP 245 and 585.

in sub basin two. Surface discharge is higher at the sub basin two under SSP 585 and under SSP 245 it is higher at sub basin six.

Components of water balance i.e evapotranspiration, ground water contribution and surface discharge under various future projection from 2021- 2040, 2041-2060, 2061- 2080 and 2081-2100 under SSP 245 and SSP 585 etc. There is variation in each sub basin components of water balance.

4.5 Spatial variation of water balance components in each sub basin under two scenarios of SSP 245 and SSP 585 from 2021 to 2100

Sub basin 1 has higher evapotranspiration than other sub basins having difference of 3.94mm under SSP 245 and 585 because of large forest area in the sub basin which enhance evapotranspiration form plants than the other basin where sub basin 6 has lower value of evapotranspiration.

While comparing the ground water discharge in the all the six sub basins,sub basin 2 has higher ground water discharge in both the scenarios of SSP 245 and SSP 585. Shallow depth of ground water table which is obtained from by the hydraulic difference between the river water level and ground water level. The difference of ground water discharge in both the scenarios of sub basin is 123.89 mm

Comparison of surface discharge in all sub basins. The sub basin 6 has higher surface discharge under both the scenarios of SSP 245 and SSP 585. The difference in the surface discharge of sub basin 6 under both the scenarios is 89.63 mm. All the sub basins contribute their stream into sub basin 6 which makes total surface discharge higher in sub basin 6.

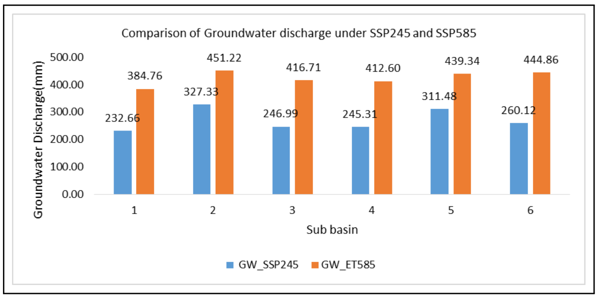


Figure 11: Comparison of groundwater in each sub basin under SSP 245 and 585.

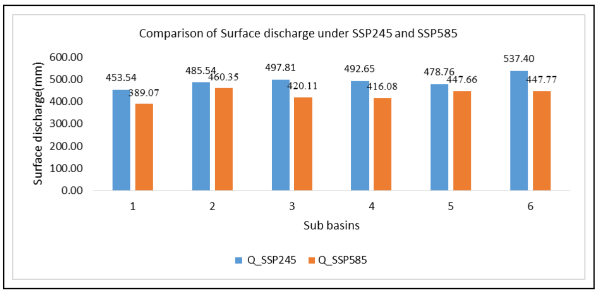


Figure 12: Comparison of surface discharge in each sub basin under SSP 245 and 585.

The percentage change in the water balance components like evapotranspiration, ground water contribution and surface discharge under SSP 585 and SSP 245 with respect to SSP 245 are shown in the bar graph.

4.6 Rainfall variation due to climate change

The average rainfall under the SSP 245 from year 2021 to 2100 is 1175.42 mm and under SSP585 is 1282.7 mm. The difference of average under SSP 245 and 585 is 107.3 mm. The future rainfall graph shows that under the SSP 585 future rainfall increases drastically from 2060 to 2100. Under SSP 245 future rainfall increase gradually from 2040 to 2100 because of climate change.

4.7 Future temperature variation due to climate change

Average of maximum temperature at SSP 245 is 29.37°C and at SSP 585 is 30.406° C also the difference of maximum

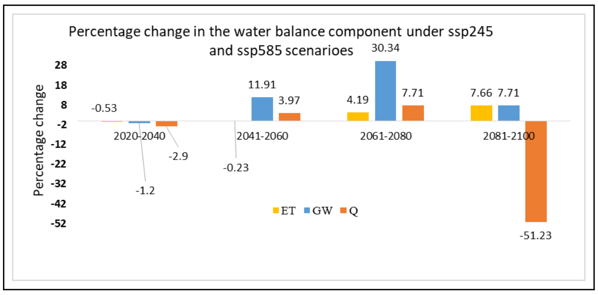


Figure 13: percentage change in water balance components of future projection from 2021-2100 under SSP 245 and 585.

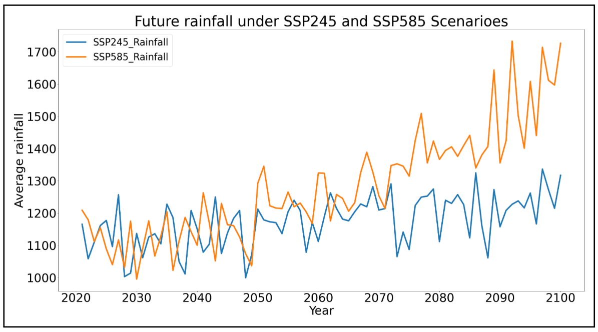


Figure 14: future rainfall projection from 2021-2100 under SSP 245 and 585.

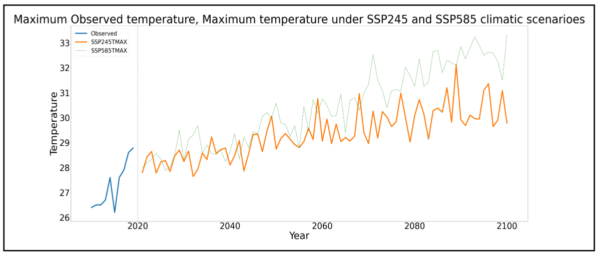


Figure 15: Maximum observed temp, maximum temp 2021-2100 under SSP 245 and 585.

temperature under both the scenarios is 1.03°C

Average of minimum temperature at SSP 245 is 5.418°C and at SSP 585 is 6.744°C also the difference of minimum temperature under both the scenarios is 1.32°C .

4.8 Future discharge variation

Discharge pattern is always higher in the SSP 585 than SSP 245. There is highest discharge under the SSP 585 in future projection of 2081to 2100. The difference in discharge under the future projection 2081 to 2100 under SSP 245 and SSP 585 is 1683.87m3/s.

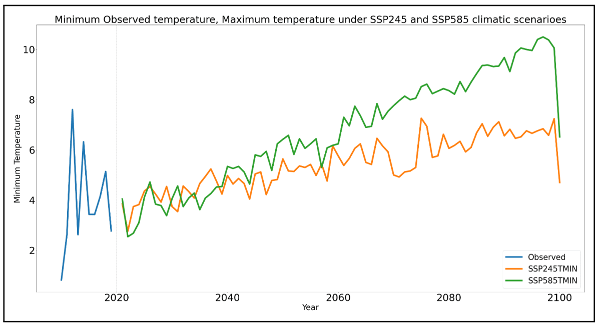


Figure 16: Minimum observed temp, minimum temp 2021-2100 under SSP 245 and 585.

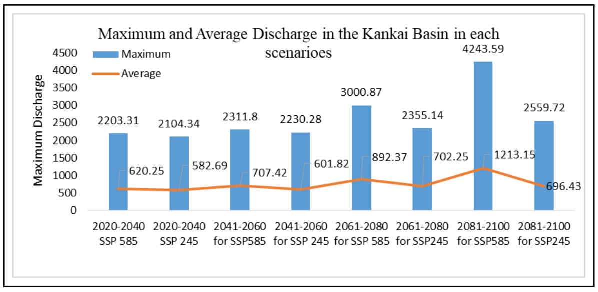


Figure 17: Maximum and avg discharge of basin 2021-2100 under SSP 245 and 585.

The lowest value of discharge is 3.39 m3/s in future projection of 2061- 2080 under SSP 245.

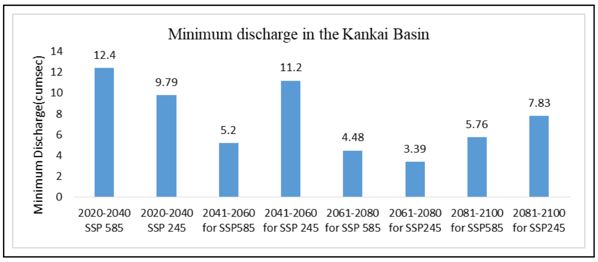


Figure 18: minimum discharge of basin 2021-2100 under SSP 245 and 585.

5. Conclusion and Recommendation

5.1 Conclusion

Understanding the variation of water balance components with the climate change, sustainable water management planning can be done.

- This study provides perception of changing trend of water balance components of basin hydrology and the simulated changes during mid-future and end of the century.
- Maximum temperature under both the scenarios will increase by 1.03°C. Minimum temperature under both the scenarios will increase by 1.32°C at the end of 2100.
- Discharge pattern is always higher in the SSP 585 than SSP 245. There is highest discharge under the SSP 585 in future projection of 2081to 2100. The difference in discharge under the future projection 2081 to 2100 under SSP 245 and SSP 585 is 1683.87m3/s.
- The average rainfall under the SSP 245 from year 2021 to 2100 is 1175.42 mm and under SSP585 is 1282.7 mm. The difference of average under SSP 245 and 585 is 107.3 mm.
- The future rainfall graph shows that under SSP 585 future rainfall would increase drastically from 2060 to 2100. Under SSP 245 future rainfall would increase gradually from 2040 to 2100.
- Flow duration curve under all the future projections from 2021 to 2100 shows that the maximum discharge would be always higher under the SSP 585 than SSP 245.

5.2 Recommendation

- This study predicts climate change in future and recommends to use adaptation and mitigation measures for predicted change.
- The increase in precipitation and other water balance components in the mid and end of century will help water resources designer and managers in making plan to fulfill water demand at lower area.
- There will be chance of flood hazard. So required preparation should be done earlier.
- The hydraulic structure should be constructed to maintain rise of water level.

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