IMPACT OF CLIMATE CHANGE ON HYDROLOGICAL REGIME OF A BASIN

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ABSTRACT: The important parameters that affect hydrologic process are climatic variables such as maximum-minimum temperature and precipitation. Impact of these variables on hydrology at basin scale is an important factor for efficient management of water resources. In this study the impact of climate change on hydrological regime of Beas basin up to Mandi was studied. The physically based semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT), was used to simulate the basin hydrology. Topographic parameters were derived from remote sensing data and land use and soil parameters were analyzed in a GIS environment. SWAT model performance was found in close agreement with the observed and simulated values with correlation coefficient (R) of 0.81 when it was ran from 1993 to 2005 period for calibration purpose. Water balance scenarios for future climatic conditions with different time periods of early century (2010-2040), mid century (2045-2070) and end century (2075-2098) were simulated using the model for climate change scenarios of representation concentration pathways (RCP) 4.5 and 8.5. Only meteorological forcings were changed during simulation and other parameters were kept same to remove the effects of land use change. A decreasing trend was observed in the total precipitation received by a decrease in 13%, thus explaining a decrease in runoff values by an average of 8% for both RCP scenarios. Also, an increasing trend was observed in the temperature values by an increase of 47%, explaining a decrease in snowmelt contribution to runoff by 50%. The results obtained in this study, suggests that climate change impacts hydrological regime of Beas basin significantly. These results obtained may help planners and policy makers in future development of the basin area with respect to water resources management. It is to be noted that, in the present study, the bias and uncertainty in the future predictions are not considered.

1. INTRODUCTION

Water influences every sphere of the environment supporting life on earth. Its varying availability in time and space is a matter of concern to the mankind since fresh water is not a ubiquitous resource. Its assessment, monitoring and management thus become important for judicious use. Water resources management requires a systems approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components (Chow et al., 1988; Maidment, 1992). Human modifications of the environment, including land cover change, irrigation, and flow regulation, now occur on scales that significantly affect seasonal and yearly hydrologic variations. A comprehensive knowledge and understanding of the various hydrological components within hydrological cycle is required in studying the implications of these changes. Further the changing climate is again putting stress on available water resources.

The impacts of climate change on hydrology are assessed based on climate change projections provided by global and regional climate models (GCMs and RCMs). In other words, climate model outputs are usually used as inputs to hydrological models for quantifying hydrological impacts. With a variety of numerical formulations and physical parameterization schemes, GCMs provide a range of climate change projections, implying that the uncertainty of the models themselves contributes to overall uncertainty when assessing climate change impacts (Chen et al., 2017). The findings of Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) published in 2013-14, are based on a new set of scenarios called Representative Concentration Pathways (RCPs). Four RCPs (RCP 8.5, RCP 6, RCP 4.5 and RCP 2.6) are defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter) pathway and level by 2100.

Changes in temperature and precipitation alter the climatic conditions and subsequently hydrological and watershed processes in the long run. The effects of changes due to climatic variability on catchment hydrological responses have been extensively carried out at watershed and river basin scales (Alexandrov and Genev, 2003). The Beas river basin covers 12,560 sq. km of the total geographical area of the country. It has faced the adverse hydro-meteorological conditions in the recent times. The reason for such changes in the hydrological regime can be attributed to the long climate variability and land cover changes in the region (Bosch and Hewlett, 1982; Gosain et al., 2006; Garg et al., 2017). The climate variability impact assessment can be best handled through simulation of the hydrological conditions that shall prevail under the projected weather conditions in an area (El-Nasr et al., 2005, Jayakrishnan et al., 2005). In the present study an attempt has been made to model and evaluate the changes in stream flow to climatic variability throughout the study area basin. The vegetation cover and related parameters were same in the simulations; only the model meteorological forcings were changed for the historical, current and future scenarios.

2. STUDY AREA

Beas river basin up to Mandi in North Western Himalayas (NWH) was selected as the study area. The Beas River was developed under the Beas project for Hydropower generation and irrigation purposes. In 1974, second phase of Pong dam, also known as Beas dam was completed followed by the first phase which is located 140 km upstream. The Pandoh Dam diverts the river through a system of channels and tunnels to the 990 MW Dehar Power Station on the Sutlej River, connecting both rivers. The Beas River which is in northern India, is an important river of Indus River system. The river rises in the upper Himalayas in central Himachal Pradesh in India, and flows in the east-west direction for 470 km to the Sutlej River in the Indian state of Punjab (Naha et al., 2016). The origin of the Beas basin is at Beas Kund in the Pir Panjal range to the north of Kullu near Rohtang Pass, at an elevation of 4085 m above sea level. The total length of its course up to Beas Dam at Pong is about 230 km. The catchment area of Beas River is about 12,560 sq. km out of which only 777 sq. km is under permanent snow. The rest of the catchment area contributes water on account of rainfall especially from the high rainfall zone of Dharamsala, Palampur and Kangra. The bulk of the discharge of this river is received between the months of June and October due to concentration of rainfall in these months. The total length of the basin is 374 km up to Mandi. The high mountain ranges of the basin varies from 2500 m to 3600 m in the south to 5000 m to 6600 m along the northern boundary. The marks of glaciation is evident along the Beas valley upstream of Kullu and towards the heads of high streams (Kumar et al., 1991). The Beas river basin with its outlet at Mandi is chosen for the study. It extends from longitudes of 76°43’56.35”E to 77°52’11.24”E and latitudes of 31°56’53.59”N to 32°24’43.821”N and covers a geographical area of 6896.39 sq. km, out of which 1226.14 sq. km is under snow and glacier.

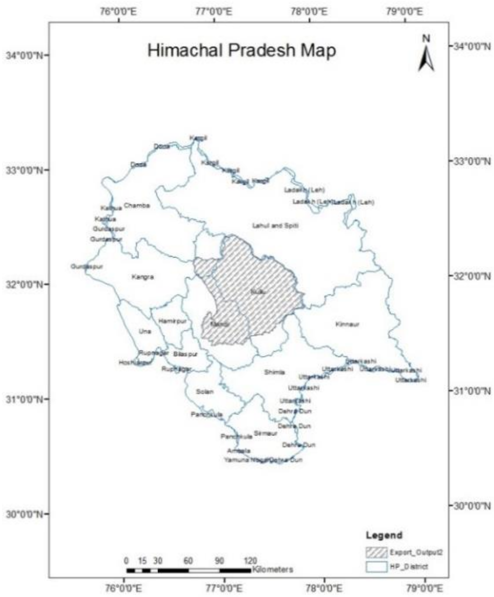


Figure 1: Location of Study Area

3. DATA USED

The study requires various inputs on meteorological condition, land use land cover (LULC), soil, topography, etc. of the basin. The ISRO Geosphere Biosphere Program (GBP) LULC map of the year 2005 was used for mapping land cover in the region. The map of the study area basin consists of ten LULC classes at a scale of 1:250,000. Snow and Ice class is the second highest covering a percent of 17.78% of the study area after the class of Evergreen Broad Leaf Forest, covering highest percent of 40.42% of the study area. The ten LULC class types found in the study area consists of: Built-Up (urban and rural), Crop Land, Plantation, Evergreen Broad Leaf Forest, Deciduous Broad Leaf Forest, Evergreen Broad Leaf Forest, Mixed Forest, Shrub Land, Grassland, Water Bodies and Snow and Ice. ASTER Global Digital Elevation Model (GDEM) was used for extracting topographic features such as elevation, slope, flow direction, flow accumulation, etc. of the study. The ASTER DEM with spatial resolution 30m was downloaded from The United Geological Survey website (www.earthexplorer.usgs.gov). Soil mapping for Indian region has been done by NBSSLUP (National Bureau of Soil Survey and Landuse Planning), Nagpur. The digitized soil map of the Beas basin were obtained at 1:250,000 scale from NBSS&LUP. Some of the associated soil properties such as texture were also derived from it. There are five soil type found in the study area: Loamy, Sandy, Loamy Skeletal, Rock Outcrops and Glaciers and Rock Outcrops.

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) has completed over the 36-year period of 1979 through 2014. The CFSR was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this period. This allows downloading daily CFSR data in SWAT file format for a given location and time period. The daily CFSR data consists of the following weather variables: Rainfall (mean) (mm), Temperature (Maximum and minimum) (ºC), Relative humidity (%), Mean Wind Speed (m/s), Solar Radiation (W/m2). The study area was selected from the website and 7 weather stations were obtained within the Study Area

Basin. The Data was collected for 36 years on daily basis from 1/1/1979 to 7/31/2014. The Observed Hydro meteorological data were collected from the Bhakra Beas Management Board (BBMB) on a daily time basis from the period of 1985 to 2012. The data consisted of daily relative humidity, precipitation, minimum and maximum temperature. The data was collected for the weather stations located at Manali, Bhuntar, Larji, Pandoh and Mandi. The observed discharge values at the outlet station of Mandi were obtained from a period of 1985 to 2007 in the measurement unit of cubic feet per second (cusecs). This data was used to setup and calibrate the hydrological model for present time period.

The future meteorological data including Climate Change scenarios of Representative Concentration Pathways (RCP) 4.5 and 8.5 were downloaded from the Coordinated Regional Climate Downscaling Experiment (CORDEX) dataset at a resolution of 44 degrees. The CORDEX data was downscaled from General Circulation Model (GCM) to Regional Circulation model (RCM) by Indian Institute of Tropical Meteorology (IITM), Pune. The gridded climate data was extracted from netCDF format using Python code. The data of daily Precipitation was downloaded in $Kg/m^2/s$ and was then converted into mm/day. The data of maximum temperature and minimum temperature was converted from kelvin units to degree Celsius. The future data of both the RCPs were downloaded for the period of 2006 to 2099. The dataset consisted of ensemble Climate model of CCCma-CanESM2. The data has been used for future hydrological components prediction using SWAT hydrological model simulations.

4. METHODOLOGY

To study the impact of climate change on hydrological regime of Beas Basin, the SWAT hydrological model has been used (Neitsch et al., 2011). Initially, the model was setup for present climatic condition for period of year 1993-2007. Then, the model was calibrated and validated. The calibrated model was then used to assess hydrological regime of the basin under future meteorological conditions. The analysis has been done for three future climatic periods: early, mid and late century.

4.1 Watershed Delineation

ArcSWAT automatically delineates a watershed into sub watersheds based on DEM and drainage network. The standard methodology, based on the eight-pour algorithm (Jensen and Domingue, 1988) is applied for automatic delineation of flow direction. The ASTER DEM with a pixel size of 30m was loaded to ArcSWAT model in ArcInfo grid format for Mandi outlet. After the DEM was imported in the model a masking polygon of the study area was created in ArcInfo grid format and was loaded in the model in order to extract out only the area of interest. The DEM was then preprocessed in order to determine the size and number of sub watersheds based on the threshold area or critical source area.

4.2 Landuse and Soil Characterization

Soil and Vegetation cover plays a significant role in the water movement process. Since the infiltration capacity of soil depends on the oil texture the highest infiltration rates are observed in sandy soils. This indicates that surface runoff is highest in clay or loamy soils which has low infiltration rates. Vegetation on the other hand acts as a barrier to flow of water. The obtained LULC and Soil classes were reclassified according to the SWAT Database codes. Also the basin was divided into 5 slope classes with an interval of 20%.

4.3 HRU Analysis and Definition

Hydrologic Response Unit (HRU) analysis menu in ArcSWAT is used for defining the LULC, Soil and Slope characteristics of the basin. The soil/slope/LULC class combinations and distributions are delineated for the watershed and the respective sub basins. Once these information have been imported and linked to the SWAT databases, HRU definition is determined using some specific criteria. As the total runoff depends on the actual hydrologic condition of each land cover/crops and soil present in the watershed, therefore the impact of each type of land use is considered. Hydrological Response Unit (HRU) distribution has been determined for the whole basin area after overlaying the soil and LULC maps, 30% threshold was considered for LULC and Soil parameters and 10% threshold was considered for Slope parameter in the HRU definition. Model creates a HRU analysis report where the information about LULC, soil and slope as per the threshold defined will be present.

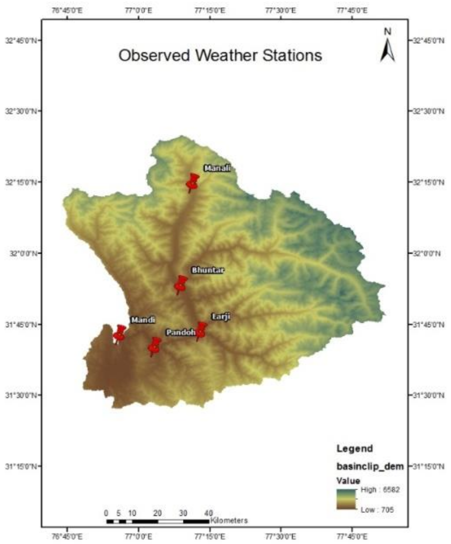


Figure 2: Map of Observed Weather Stations

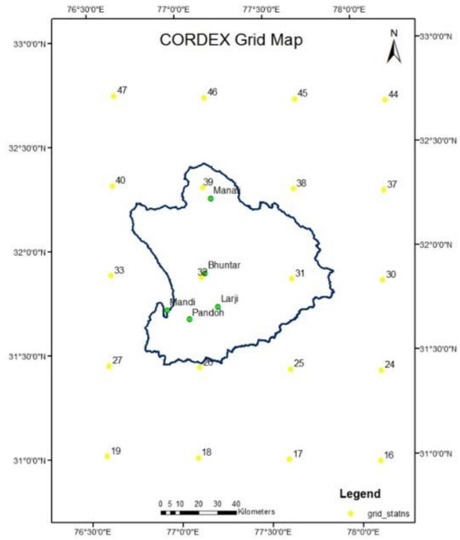


Figure 3: Map of CORDEX Weather Stations

4.5 Weather Generator Data

Weather data were collected from different sources for the running the model in different time scenarios. For the present time period study (1979 to 2013) were collected from www.swat.tamu.edu website and the observed Present data were collected from the Bhakra Beas Management Board (BBMB). For Future Climate study, the future climate data was downloaded from CORDEX at a resolution of 0.44°. This data was downscaled from GCM to RCM by IITM, Pune.

4.6 Defining Elevation Bands

Orographic precipitation is one of the major aspect in snow fed mountainous catchments (Singh and Kumar, 1997). Snow accumulation and melt processes in mountainous watersheds are strongly influenced by changes in elevation (Pomeroy and Burn, 2001). Fontaine et al. (2002) showed that definition of elevation bands within the model's sub watersheds can enhance simulation performance in watersheds with complex topography and large elevation gradients. SWAT allows for defining 10 elevation bands in each sub basins to account for orographic effects on both temperatures and precipitation (Pomeroy and Burn, 2001; Kumar et al., 2015). Then edition of sub basin wise snow parameters like elevation bands, fractional elevation bands area, temperature lapse rate, etc has been done. The temperature lapse rate was given an input of -0.65°C per km. Also, the entire study area basin was divided into six elevation bands ranging from 705m to 6582m with an interval of 1000m.

4.7 Editing Reservoir Data

Reservoirs are impoundments located on the main channel network of the watershed. Reservoirs receive loadings from all upstream sub basins. For the present study, Pandoh Dam, an embankment dam lies on the course of Beas River in Mandi district of Himachal Pradesh, India. The water is used for power generation at the Dehar Power House before being discharged into the Sutlej River, connecting both the rivers. The power house has an installed capacity of 990 MW. The system diverts 256 cumecs (9000 cusecs) of Beas waters to the Satluj River. The reservoir input files contains input data to simulate water and sediment processes. Data such as the month in which reservoir became operative (MORES), reservoir surface area when reservoir is filled to the emergency spillway (RES_ESA), initial reservoir volume (RES_VOL) and many more are given as input in the model.

4.8 Running SWAT

After preparing all the datasets (Watershed delineation, Landuse, slope, soil, weather generator, elevation bands) and updating all the input files, SWAT simulation has been done for different time periods according to different climate change scenarios on a daily basis. For the present study the model was ran seven times with climate data of present time (1990 – 2007), Early Century (2006 – 2040), Mid Century (2041 – 2070) and End Century (2071 – 2098) for both the scenarios of RCP 4.5 and RCP 8.5. The present data simulations was ran with a warm up period of three years and the future climate data simulations were ran with a warm up period of four years.

4.9 Model Calibration

Model calibration is the process whereby the selected parameters and variables of the model are adjusted to make the model output match observations (Refsgaard, 1997; Abbaspour et al., 2007). Its main purpose therefore is to obtain an economical and reproducible method of identifying a parameter set for a particular catchment under particular conditions which gives the best possible fir between the simulated and observed stream flows for a particular calibration i.e. the calibrated parameter set aims at minimizing the difference between simulated and observed stream flows (Peterson and Hamlett, 1998; Arnold et al., 2012). In the present study, the ArcSWAT model was calibrated for the year 1993 to 2005 based on the BBMB observed discharge at the outlet station of Mandi and the estimated discharge or flow out values obtained after simulation. The basin surface runoff at outlet Mandi was calibrated with a coefficient of determination (R^2) value of 0.6636 and a correlation coefficient (R) of 0.814. For the present study, the simulation from year 2006 to 2007 was used for the validation of the model. The calibrated model was then used for future climatic condition simulation using both RCP 4.5 and RCP 8.5. The difference in the results obtained for overlapping period of year 2006 to 2007 was considered as Bias for the validation of simulation.

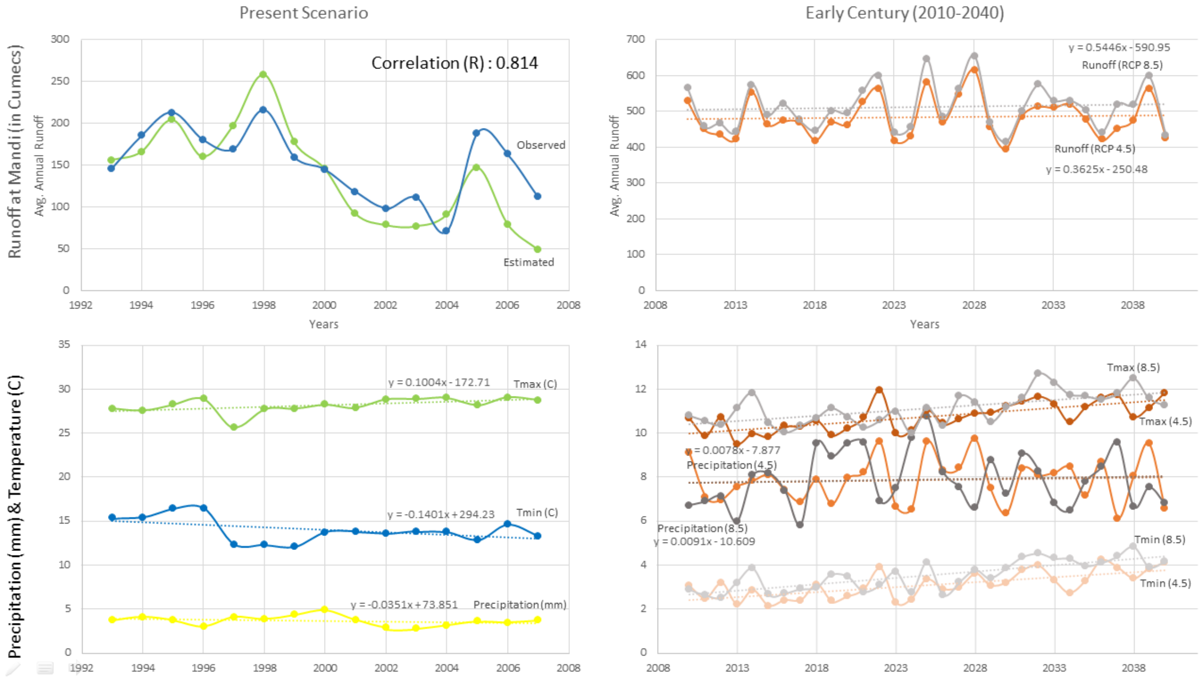
5. RESULTS

The impact of climate change on hydrological regime of Beas Basin is studied. The SWAT model was setup for present climate condition for period from 1993 to 2007. The basin surface runoff at outlet Mandi was plotted against the observed discharge at the outlet on a yearly and monthly basis from year 1993 to 2005 (Figure 4). The two values have a coefficient of determination (R^2) value of 0.664 and a correlation coefficient (R) of 0.814. The observed output of decreasing runoff can be attributed to the decrease in precipitation over the years of 2002 to 2004. The impact of increasing maximum temperature and a decreasing minimum temperature has little impact on the runoff in the basin. The high correlation under calibration phase provided impetus to study impact of climate change on this particular basin under various climatic scenarios.

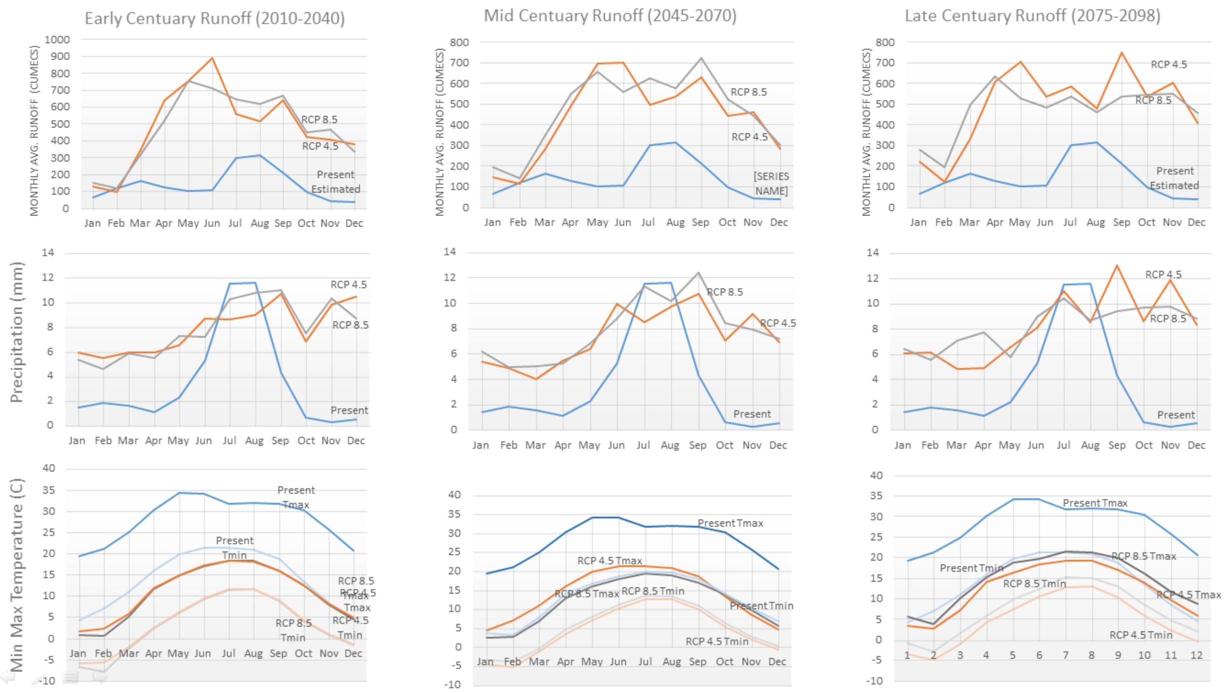
5.1 Impact of Climate Change on Beas Basin Hydrology

The future climate study was divided into three parts: Early Century (2006 – 2040), Mid Century (2041 – 2070) and End Century (2071 – 2098). However, while modeling a warm up period of 4 years were given to all the simulations. Thus, the results obtained are from 2010 to 2040 for Early Century, from 2045 to 2070 for Mid Century and from 2075 to 2098 for End Century. The model was ran for all three time period using climate change scenarios of RCP 4.5 and RCP 8.5 and results obtained for each are discussed subsequently.

Early Century Simulation from years 2006 to 2040 was done in ArcSWAT using a warm up period of 4 years. The model was ran both the climate change scenarios (RCP 4.5 & 8.5). The runoff obtained at outlet Mandi is plotted as shown in the graph below. The graph of temperature and precipitation trend is also plotted. It is observed that the surface runoff has an increasing trend for early century. This can be attributed to the increasing trend in the annual precipitation for the early century. Also the temperature has an increasing trend, thus leading to more snow melt from the snow fed regions of the basin area, thus increasing the surface runoff. The surface runoff values of early century and present were also compared using monthly average over the years and compared against the monthly average values of precipitation (Figure 4). It is observed that there is an increase in the amount of total precipitation received per month for the future scenarios of 4.5 and 8.5 under this time period. Thus, it can be said that the increase in monthly runoff values are due an increase in the monthly precipitation rate. For Mid Century simulation, the period from from years 2041 to 2070 was hydrologically simulated using ArcSWAT for both the climate change scenarios. It is observed that the surface runoff has a decreasing trend for midcentury. This may be due to the decreasing trend in the annual precipitation for the midcentury. Moreover, the temperature has also an increasing trend, the enough snow cover area may not present for snowmelt to occur thus leading to less snow melt from the snow fed regions of the basin area, thus decreasing the surface runoff. The surface runoff values of Mid-century and present were also compared using monthly average over the years and compared against the monthly average values of precipitation (Figure 4). It is observed that there is a decrease in the amount of total precipitation received per month for the future scenarios of 4.5 and 8.5. Thus, it can be said that the decrease in monthly runoff values are due an decrease in the monthly precipitation rate and increase in temperature. End Century Simulation were carried out for time period from year 2071 to 2098 for both the climate change scenarios. It is observed that the surface runoff has a decreasing trend for End century. This might have resulted due to the decreasing trend in the annual precipitation for the late century. Simultaneously, the temperature has an increasing trend, which may result in less snow fall leading to less snow cover area. The reduction in snow fall and snow cover will generate less snow melt, thus decreasing the surface runoff. The surface runoff values of End century and present were also compared using monthly average over the years and compared against the monthly average values of precipitation (Figure 4).



Present Scenario
Correlation (R) : 0.814
Runoff at Mandi (in Cumecs)
Avg. Annual Runoff
Observed
Estimated
Years
Early Century (2010-2040)
y = 0.5446x - 590.95
Runoff (RCP 8.5)
Runoff (RCP 4.5)
y = 0.3625x - 250.48
Avg. Annual Runoff
Years
Precipitation (mm) & Temperature (C)
y = 0.1004x - 172.71
Tmax (C)
y = -0.1401x + 294.23
Tmin (C)
y = -0.0351x + 73.851
Precipitation (mm)
Tmax (8.5)
Tmax (4.5)
y = 0.0078x - 7.877
Precipitation (4.5)
Precipitation (8.5)
y = 0.0091x - 10.609
Tmin (8.5)
Tmin (4.5)



Early Centuary Runoff (2010-2040)
Mid Centuary Runoff (2045-2070)
Late Centuary Runoff (2075-2098)
MONTHLY AVG. RUNOFF (CUMECS)
RCP 8.5
RCP 4.5
Present
Estimated
[SERIES NAME]
Precipitation (mm)
Present
Min Max Temperature (C)
Present Tmax
Present Tmin
RCP 8.5 Tmax
RCP 4.5 Tmax
RCP 8.5 Tmin
RCP 4.5 Tmin
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

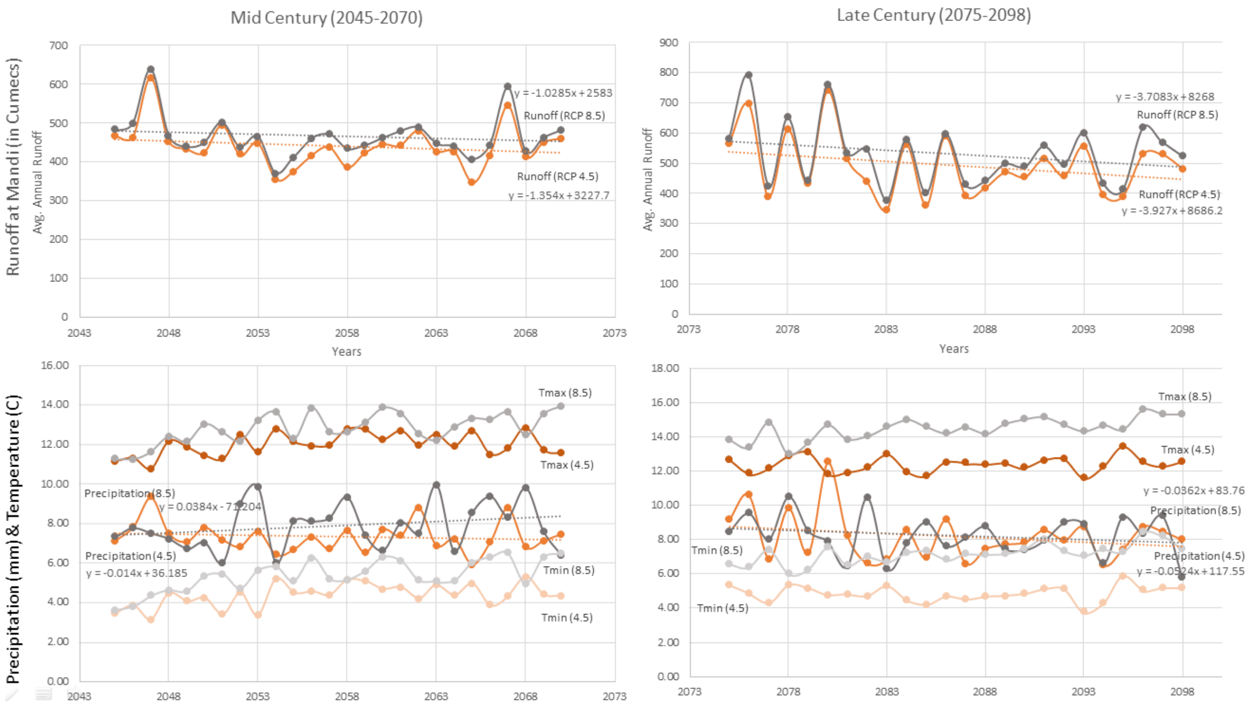


Figure 4: Average Monthly Runoff; Precipitation; and Min. & Max. Temperature Change under each Time Period for each Climatic Scenario

5.2 Change in Snowfall and Snowmelt Results

The SWAT model uses temperature based snowmelt runoff model for estimation of snowmelt; and based on elevation and temperature lapse rate, it simulates snowfall. The basin surface runoff has been estimated by incorporating snowmelt by thorough editing of sub-basin wise snow elevation bands, its fraction area in the sub-basin and the temperature lapse rate. The trend of both snowfall and snow melt was studied for the present study from 1990 to 2007. The snowfall and snowmelt studies were conducted at the station of Bhuntar. A decreasing trend was observed for both snowfall and snowmelt for the present climatic conditions.

From the LULC map of the Beas basin area, we can see that snow and glaciers cover the second largest land area in the basin, with a percentage basin area of 17.78%. Snow and glaciers form an important land use and land cover type in the basin study. Thus, snow would play an important role in the impact of climate change on the hydrology of the basin (Fontaine et al., 2002). Hence, snow studies were included exhaustively in the present study. Also, the hydrological model of ArcSWAT 2012 allows giving snow inputs in terms of elevation rate and temperature lapse rates, and gives snowmelt values in runoff in the model output results. snowfall and snowmelt were studied for the hydrological simulation of future climatic data of both IPCC scenarios of 4.5 and 8.5. The model was simulated for three future time series of early, mid and end century. The snowfall and snowmelt results of the hydrological simulation done are presented in the graphs below for the station of Bhuntar. For the present study, a decreasing trend in both the Snowfall and Snowmelt values is observed for all the future climatic scenarios of early, mid and end century, for both the RCPs 4.5 and 8.5 scenarios. This decreasing trend of Snowfall and Snowmelt is in continuation with the trend observed for the present climatic conditions. Thus, it can be said from the results that in the future there might be a decrease in the snow cover area, due to a decrease in the receiving amount of snowfall itself. This can be attributed to an increase in the temperature values in the future. Due to an increase in temperature, there is no sufficient minimum temperature available for the formation of snow. Also, due to a decrease in the snow cover areas; there is a decrease in the snowmelt contribution to the surface runoff.

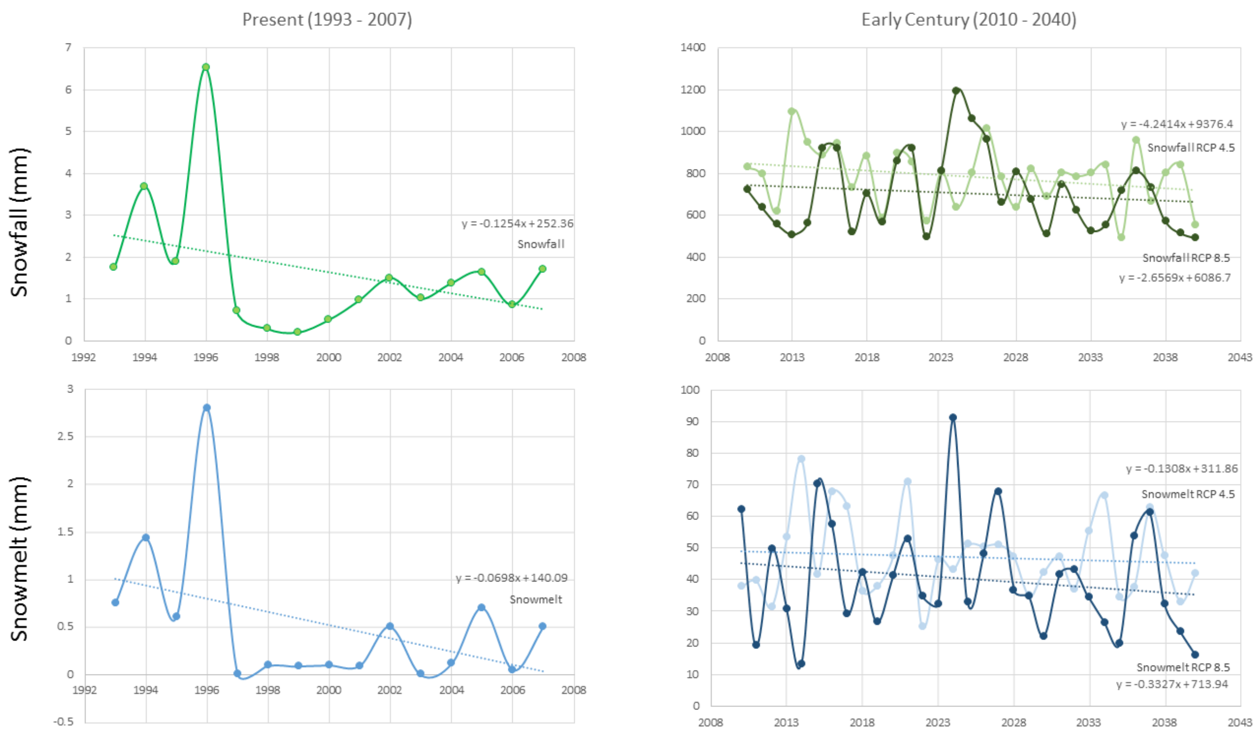


Figure 6: Average Annual Snowfall and Snowmelt graph results for Present and Early Century

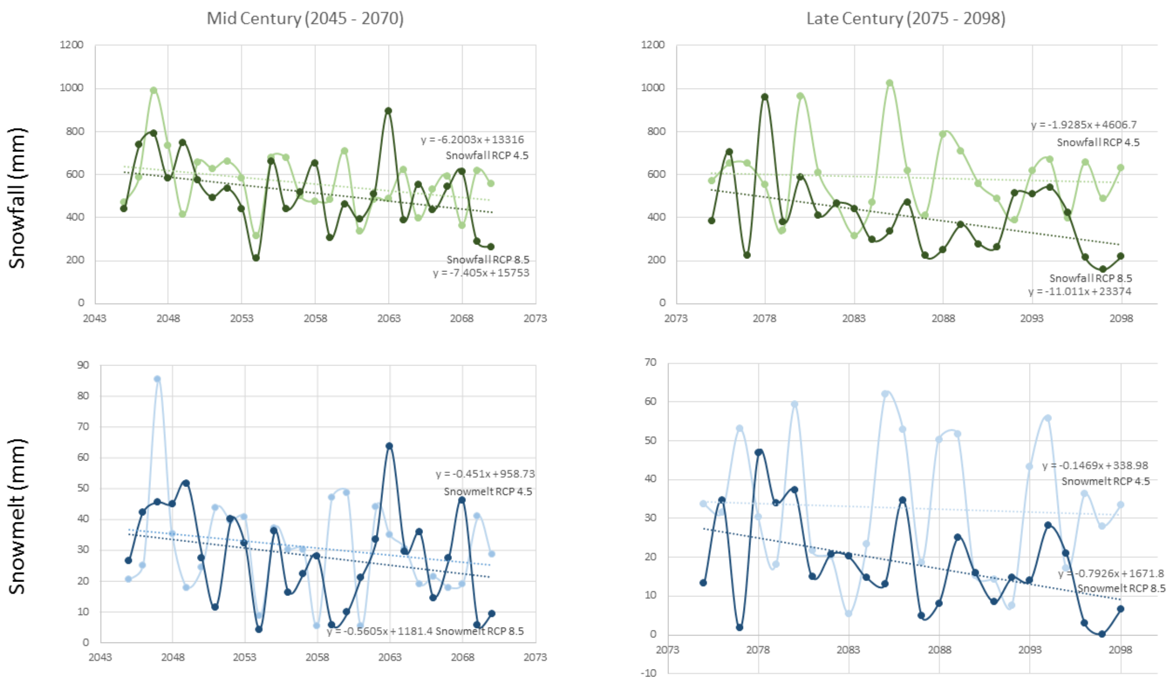


Figure 7: Average Annual Snowfall and Snowmelt graph results for Mid and Late Century

CONCLUSIONS

Remote Sensing and Geographic Information System (GIS) plays an important role in deriving inputs for hydrological modelling of a large basin and in studying the impacts of climate change on the basin regime. Climatic variables play an important role in watershed runoff and stream discharge pattern over time. Changes in temperature and precipitation are adversely affecting the hydrologic processes within watershed. A semi-distributed hydrological modelling usually offers an efficient solution to evaluate the long term hydrological changes by allowing quantification of changes in streamflow patterns. This study attempts to model the hydrology of Beas basin up to Mandi using a physically based, semi-distributed SWAT hydrological model and assess impact of climate change on hydrological regime over the entire basin. The SWAT hydrological model was simulated for both present and future climatic conditions. The model was calibrated using estimated model outputs from 5 weather stations of BBMB and the observed discharge at Mandi Bridge. The model was calibrated from years 1993 to 2005. The model validation was performed using estimated model outputs from 5 weather stations of Bhakra BBMB and the observed discharge at Mandi Bridge for period from year 2006 to 2007. Further the calibrated model was used to simulate for three future time series of early-century, mid-century and End-century forced by future meteorological CORDEX data of RCP 4.5 and RCP 8.5scenarios. The runoff outputs were compared for both ideal scenario of RCP 4.5 and extreme scenario of RCP 8.5. The following conclusions can be obtained for the hydrological simulation of Beas Basin up to Mandi outlet: model was calibrated with correlation coefficient (R) value of 0.81; decreasing trend in runoff (cumecs) and precipitation was observed throughout present and future cimatic conditions; decreasing trend in snowfall (mm) and snowmelt (mm) was observed throughout present and future climatic conditions. This may be due to an increasing trend in temperature and subsequent decrease in precipitation values. The differences in the results might also be due to the large bias in future predictions. Thus, it can be concluded that climate change impacts hydrological regime of the basin significantly. These results can help hydro project planners and policy makers in future development of the basin area with respect to water demand and water availability. Moreover, suitable adaptation strategies can be planned accordingly. It is to be noted that the corrections for the bias and uncertainty in future prediction on meteorological parameters has not been carried out, in the present study.

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