Assessment of Climate Change Impact on Hydrology of Hunza River Basin

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Abstract*: Assessment of climate change impact on streamflow is crucial for the Hunza River, which contributes significantly to the Upper Indus Basin. Projected changes in streamflow will affect the agriculture, hydropower, and fisheries of the Hunza River Basin under climate change. This study aims to detect the changes in streamflow in response to climate change in the semi-arid watershed. Historical climate and flow gauging data were collected from various departments, and bias correction was performed on future climatic data using four Regional Climate Models (RCMs) under two Representative Concentration Pathways (RCPs 4.5 and 8.5). The Soil and Water Assessment Tool (SWAT) was developed for the Hunza River Basin and was successfully calibrated and validated. Subsequently, the impact of climate change on streamflow in near future (2011~2040), mid future (2041~2070) and the long-term future (2071~2099) was analyzed using baseline data (1981-2010). Results show that the projected changes in streamflow are expected to behave differently on monthly, seasonal and annual basis. The peak flows, time to peak, median and low flows are expected to change significantly under the influence of climate change. These outcomes suggest that it is imperative to consider the impact of climate change on hydrology of Hunza Basin to form suitable strategies for planning and management of river basin.

***Keywords:* Climate Change, Hunza River Basin, Hydrology.**

I. INTRODUCTION

The rise in global average temperature by 0.6°C was recorded during the 20th century [1]. As per estimates are drawn out by climate models [2-10], world average temperature is projected to rise by 4.0°C by the end of 21st century [11]. To understand the impacts of climate on hydrology and water resources, trustworthy extrapolation of climate trends is the pre-requisite [12]. SRES scenarios [13-20] were employed by many authors to analyze the influence of climate change. Contemporarily, these SRES scenarios are rendered to be obsolete. To study the impacts of climate change, in most of the research projects in the Upper Indus Basin to date, a few GCMs under SRES scenarios have been employed [21-27]. These scenarios overrate the accessibility of resources and are least likely to be used on future outputs from fossil fuels [28]. SRES are now being replaced by Representative Concentration Pathways (RCPs) to address the shortcomings of the former. The RCPs do not deal exclusively with emission scenarios socioeconomic limitations. Nevertheless, these deal with policies related to demography, technology and economy, and further challenges related to mitigation and adaptation. One of many benefits of RCPs is that it gives refined resolution that helps perform comparative studies in regional and local domains [28]. The factors leading to ambivalent trend of climate change are model uncertainty, climate variability and doubtful scenarios [29]. Upper Indus Basin and its tributaries have been studied regarding the change in the climate [23, 30-40]. Merely, a few studies anticipated future climate employing GCMs [39-44]. The trends of rainfall from 1961 to 1999 for Upper Indus Basin were studied by Akhtar et al. A decadal increment in rainfall of 22, 103, and 120 mm was reported at Skardu, Shahpur, and Dir stations respectively [44]. Moreover, a rise in average temperature from 0.3 to 4.8°C and in precipitation from 19 to 113 % is expected [44]. Some GCMs were employed under SRES scenarios in that study. To plug the gap found in that literature, this study is of great significance. The following questions have been addressed as a result of this study: What is the upcoming future about the climatic conditions of Hunza Watershed? What change in the stream flows of Hunza River is expected when studied under RCPs using RCMs? ACCESS, CNRM, MPI, and NorESM are the four RCMs that were used in this study. This selection is made under two RCPs 4.5 and 8.5 to predict the forthcoming streamflow by using SWAT hydrologic model. The first philosophy behind this study is to assess the wide range of probabilities in upcoming climate. The second tantamount to this study is how RCPs can be of help to determine the ambiguity pertaining to emission scenarios. The real beneficiaries of this study will be those who are deemed to plan and make decisions regarding optimal water management assignments taking effects of climate change into account.

II. MATERIALS & METHODS

A. *Study Area*

The total watershed area of the Hunza River Basin is 13, 735 km^2 and it is located on the northeastern side of Pakistan (Figure 1). It comprises three kinds of slopes namely undulating lands (0-3%), steep slopes (8-30%) and mountainous land (>30%). Hunza watershed mainly comprises of steep slopes and mountainous terrain [45].

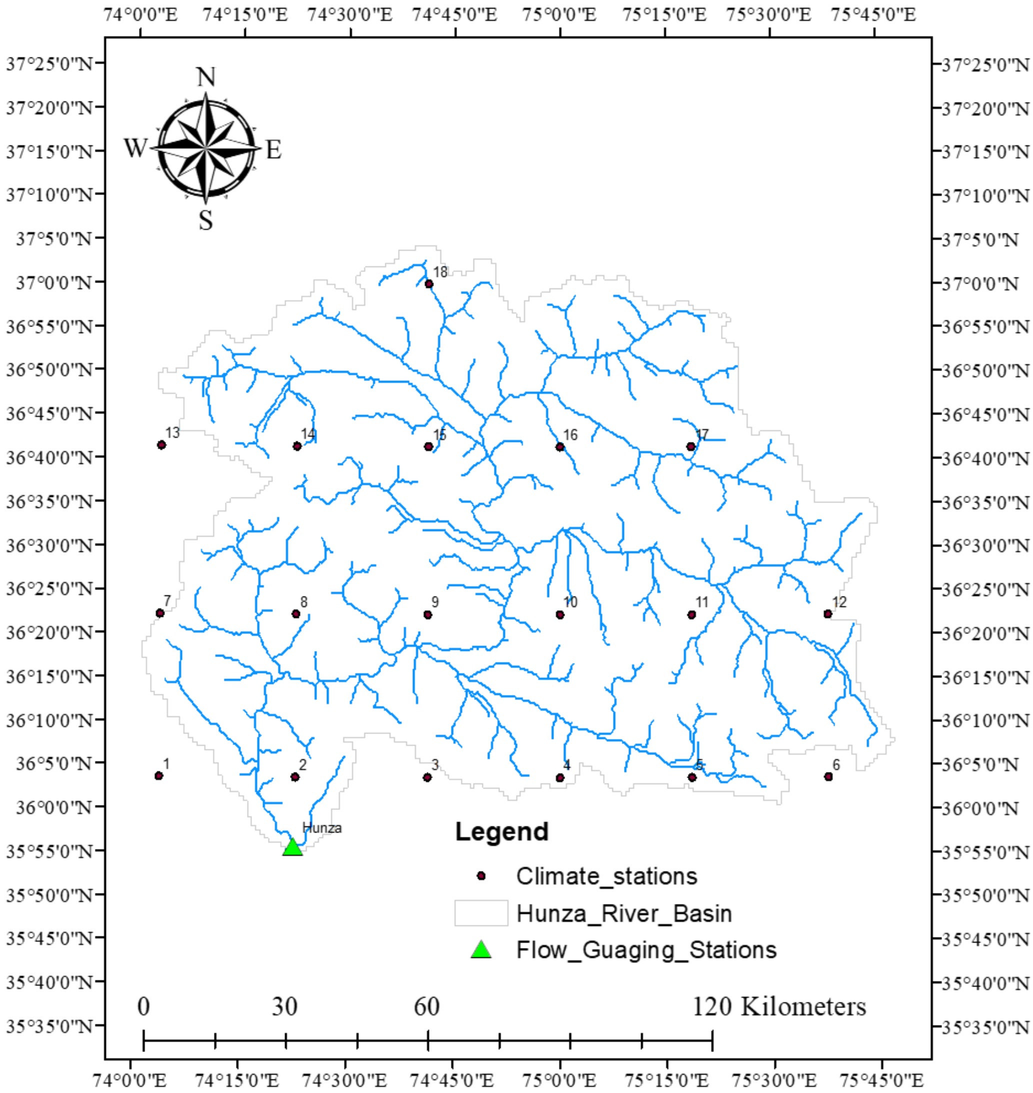


Fig. 1: The Map of Hunza River Basin with the climate stations and flow measuring station.

Hunza river carries the principal amount of water from May to September. The peak flow is generally observed in the month of July. The amount of flow during period between November to April is very low, even less than 100 m^3/sec. During May that due to snowmelt, the amount of water in the river started rising and reaches to peak in mid-July. During period from May to September, flow which passes through the Hunza River is almost 90% of the total flow. Remaining 10% passes through the river in other 6 months. It is the variation in the altitude which decides the climate of the basin. The climate variation is observed as altitude varies from North to South. Significant variation can be observed as we move from the subtropical part in the southern side of the basin having elevation less than 1,500m to the northern side where elevation goes up to 5,000 m. While going above this elevation of 5,000m the temperature goes below freezing point.The average monthly precipitation and temperature prevailing in Hunza watershed are shown in figure 2. For Hunza watershed, mean annual $T_{max,}$ $T_{min,}$ and Precipitation are -1.88°C, -12.69 °C and 977 mm. Four seasons in the watershed are named as follows: Winter(DJF), spring(MAM), Summer(JJM) and Autumn(SON). average seasonal Tmax, Tmin, and precipitation in Hunza Watershed are -11.3 °C, -23.40 °C and 240 mm, -3.00 °C, -13.77 °C and 410 mm, 8.56 °C, -1.13 °C and 185 mm and -1.99 °C, -12.68 °C and 141 mm. Generally viewed that the watershed observes bi-modular distribution of precipitation. The first larger peak is observed in March when there is snowfall and second lower peak comes in August when there is monsoon rainfall.

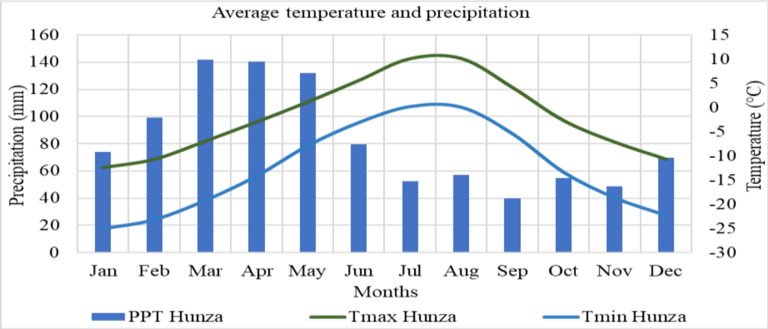


Fig. 2 : Average monthly temperature (Tmax and Tmin) and precipitation (1981-2010) in Hunza River Basin.

B. Data

i. Historical observed data

a. Meteorological Data

The meteorological data including Tmax, Tmin, and precipitation was collected from National Centers for Environment Prediction's Climate Forecast System Reanalysis (CFSR). The list of meteorological stations and their locations are being shown in Table1 and Figure 1, respectively. It is found that rain in watershed is less than total flows if only data from weather stations is used. It cannot happen if analysis made on pragmatic grounds. Hence, climatic condition of mountainous areas cannot be assessed if only weather stations are relied upon.

Data from CFSR can be used where data available is found insufficient [46, 47]. CFSR data for 18 stations were used in this study. Daily precipitation, Tmax, and Tmin having a resolution of 0.50º x 0.50º are available from 1979 to 2010 on website (http://globalweather.tamu.edu).

Table 1. List of climate stations.

No.	Name	Latitude N	Longitude E	Elevation m, MSL	Theissen Factors
1	p361741	36.06	74.06	2102	0.0095
2	p361744	36.06	74.38	4444	0.0539
3	p361747	36.06	74.69	3819	0.0274
4	p361750	36.06	75	4601	0.0379
5	p361753	36.06	75.31	4387	0.0405
6	p361756	36.06	75.63	5317	0.0250
7	p364741	36.37	74.06	5133	0.0331
8	p364744	36.37	74.38	5051	0.0719
9	p364747	36.37	74.69	4562	0.0707
10	p364750	36.37	75	4936	0.0707
11	p364753	36.37	75.31	5133	0.0719
12	p364756	36.37	75.63	5734	0.0613
13	p367741	36.69	74.06	4055	0.0177
14	p367744	36.69	74.38	4725	0.0853
15	p367747	36.69	74.69	4761	0.0707
16	p367750	36.69	75	4301	0.0977
17	p367753	36.69	75.31	4677	0.0979
18	p370747	37	74.69	4129	0.0568

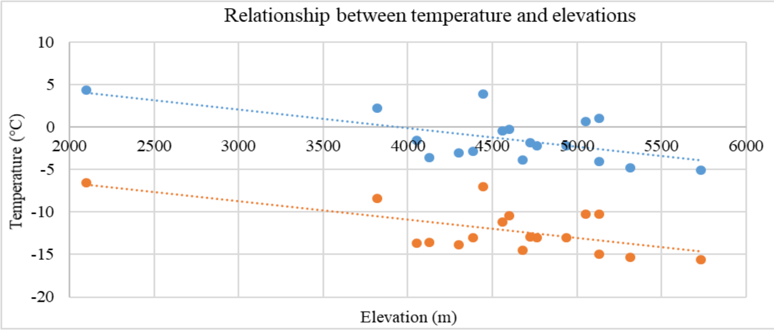


Fig. 3: Correlation of temperature (Tmax and Tmin) and elevations of the Hunza River Basin.

The lapse rate of Hunza River Basin was estimated using the climatological temperature data. Temperature decreases with the increase in elevation. The relation between mean daily temperature and the altitude was used to calculate the lapse rate of the basin. Figure 3 portrays a clear picture to define the relation between temperature and altitude. The lapse rate was noted as 2.2°C/km for the study area.

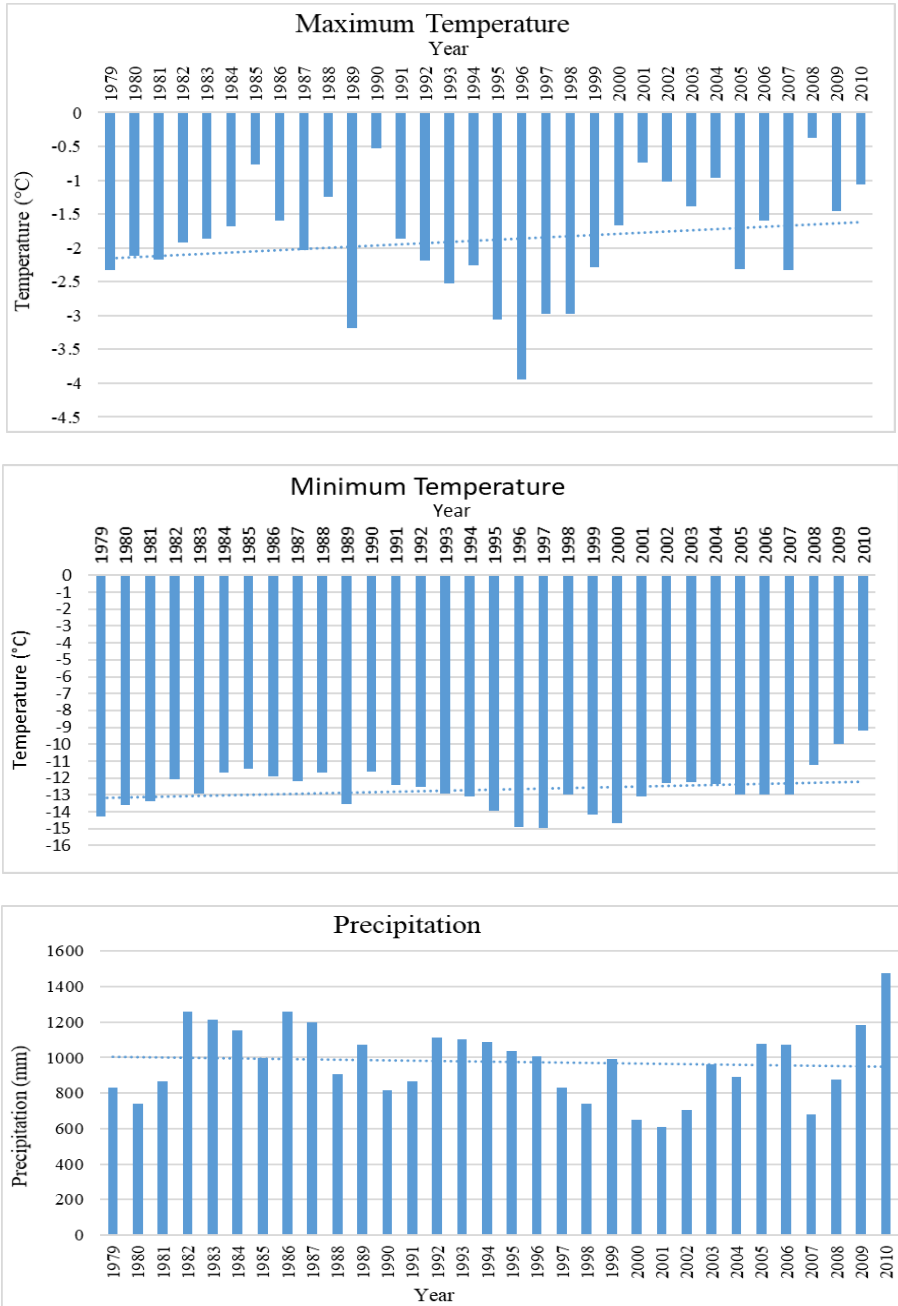


Fig. 4 : Historical trend of climate (Tmax Tmin, and Precipitation) in Hunza Watershed.

In figure 4 it becomes evident that temperature has risen in the historical period. Tmax increases at a higher rate than that of an increase in Tmin.

b. Discharge Data

Figure 1 shows the river network of the Hunza River Basin along-with the flow-measuring station. The daily streamflow data from flow-measuring station at Hunza River at Doyian was collected (Table 2). The mean monthly streamflow (1979-2004) from the Hunza River Basin is presented in Table 3.

Table 2. Details of Flow-measuring station in the Hunza River Basin.

No.	Station	River	Latitude N	Longitude E	Elevation m, MSL	Area km^2	observation period
1	Hunza (Doyian)	Hunza	35.93	74.38	1370	13,157	1979-2004

The average monthly runoff of the Hunza River Basin varies between 40 and 1,018 m^3/s. The minimum and maximum flow occur in March and in July, respectively. Changes in the temperature and precipitation lead to remarkable changes in the stream flows (Table 3).

Table **3.** Average monthly streamflow (m^3/s) in Hunza Watershed (1979-2004).

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (J-D)
Hunza (Doyian)	48	43	40	56	179	518	1018	1004	461	145	73	56	303

c. Spatial Data

- *Digital Elevation Model (DEM)*

The DEM data was made available from the Shuttle Radar Topographic Mission (SRTM) of NASA. The SRTM DEM bears a resolution of 30 x 30 m on the equator and were sent in mosaiced 1-arc second product pans for convenient download and application. The basin and sub-basins in the SWAT model are explained mechanically. Runoff as a result of snow-melt in Hunza Basin is the major contributor of the UIB, whose area exceeds 70 % above 4,000 m from MSL. DEM analysis presented that maximum, minimum, average elevation and the standard deviation is 7,797 m, 1424 m, 4,515 m and 942, respectively (Figure 5 and 6).

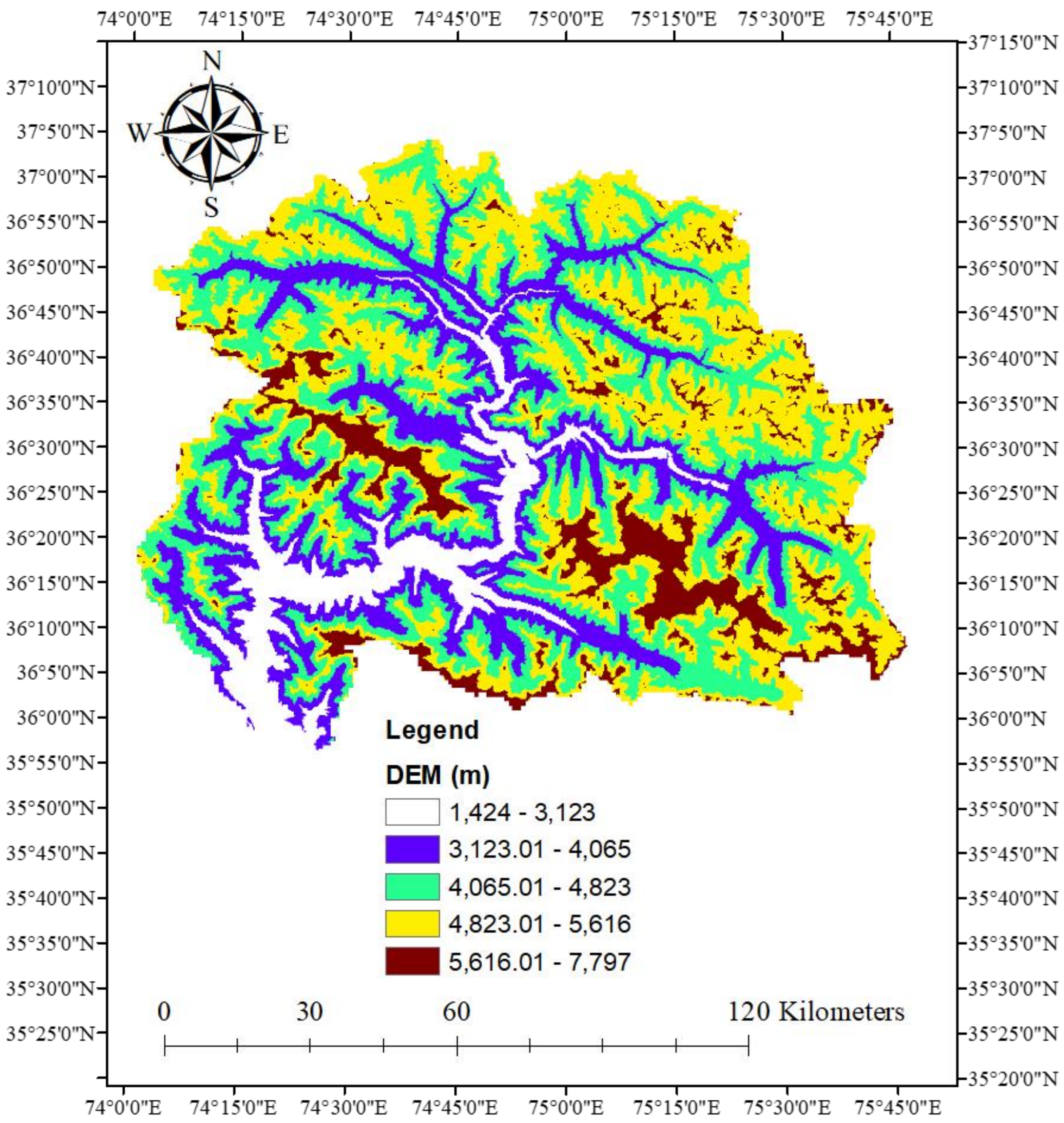


Fig. 5:.DEM of the study area

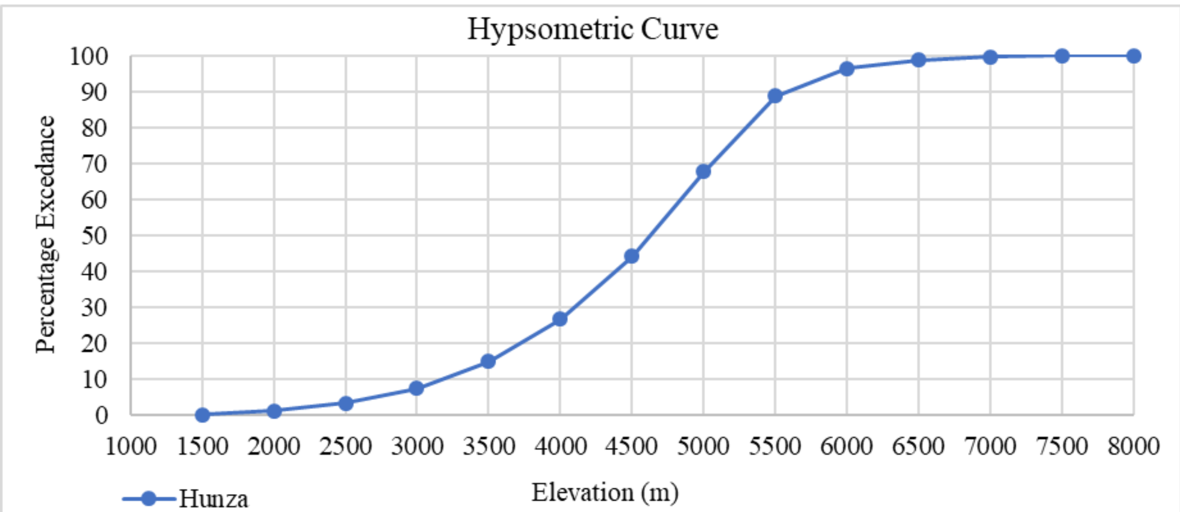


Fig. 6: Hypsometric Curve of the study area

Soil Data

Data related to soil was obtained from the Digital Soil Map of the World (DMSW). The Soil data was downloaded from FAO Soils Portal for South Asian countries and their soil features were found out by the Food and Agriculture Organization of the United Nations (FAO) [45]. The soil data were characterization into four groups (Table 4).

Loam is the Dominant soil class which spreads over 53.31 % of the area of the basin. The sand, silt, and clay of every soil group along-with the other characteristics are presented in Table 4. The slope analysis of the study area is shown in table 5.

Table 4. Soil constituents and parameters in Hunza River Basin.

Soil	SNAM	TEXTURE	Soil Bulk Density (g/cm3)	Hydrologic Group	Soil Available Water Capacity (mm/mm)	Percentage of Basin Area (%)	CLAY	SILT	SAND
3503	I-B-U-2c-3503	LOAM	1.1	C	64	2.72	26	30	44
3731	I-X-2c-3731	LOAM	1.4	D	71	0.00	22	33	45
3733	I-Y-2c-3733	LOAM	1.4	D	71	50.59	23	39	38
6998	GLACIER-6998	UWB	2.5	D	10	46.69	5	25	70

(FAO soil classification, 1995)

Table 5. Slope distribution of the Study Area.

Slope (%)	Area (%)
0 to 3	0.84
3 to 8	3.51
8 to 30	16.87
30 to 80	58.73
80 to 999	20.05

d. Landuse Data

World images of landuse with a grid resolution of 500 x 500 was made available from The MODIS dataset.

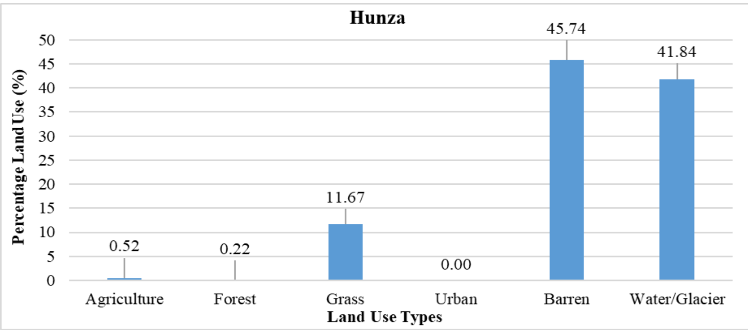


Fig. 7 : Distribution of various land-use types in the study area.

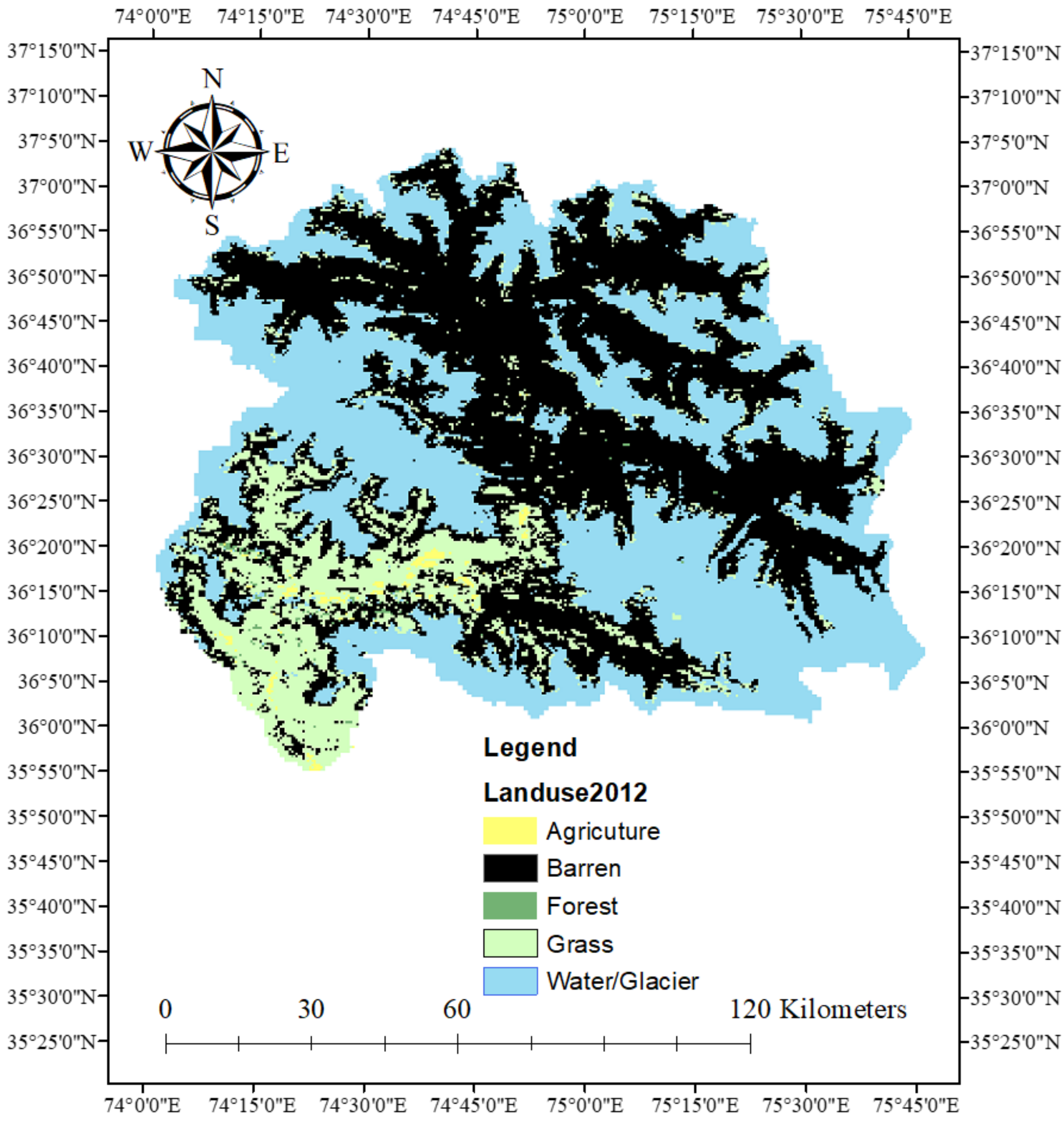


Fig. 8 : Land use image of the Hunza Watershed.

Hunza Basin consists of different types of land covers (Figure 7). The major part of the land in the Hunza Watershed is left Barren, which spreads over 45.74 % of the catchment. The other classes in watershed consist of water or glaciers (41.84 %), grassland 11.67 %), agriculture (0.52 %), forest (0.22 %), and urban (0.002) (Figure 8).

e. Future climate data

The following website http://climate4impact.eu/impactportal/data/advancedsearch.jsp. was used to download the required future climate data for the study area.

In the year 2000, worldwide various climate stations cover resolutions of 0.5°×0.5° and updated the datasets [48]. These RCMs datasets Precipitation, Tmax & Tmin were downloaded for selected RCPs. The compelling intensities of the said two RCPs are 8.5 W/m^2 and 4.5 W/m^2, in order, almost obeying the high and medium condition. The RCMs employed for climate prediction in the study area are shown in Table 6. The time period from 1979 to 2100 is covered by these RCMs under two RCPs, and the period is distributed into as following: base period (1981-2010) and future three-time slices (the 2020s: 2011–2040, the 2050s: 2041–2070 and the 2080s: 2071–2100).

Table 6. Four RCMs used under RCP 4.5 and 8.5 from the Commonwealth Scientific and Industrial Research Organization.

Model	Country	Emission Scenarios RCPs	Spatial Resolution
ACCESS	Australia	4.5 and 8.5	0.5° × 0.5°
CNRM	Australia	4.5 and 8.5	0.5° × 0.5°
MPI	Australia	4.5 and 8.5	0.5° × 0.5°
NorESM	Australia	4.5 and 8.5	0.5° × 0.5°

C. *Methodology*

Representativeness, vintage, validity, and resolution of results are the parameters which play to decide the RCMs. As to cover wide range of uncertainties, the combination of RCMs can be selected keeping in view that these selected RCMs are not essentially the best climate models for the study area [49]. Linear scaling (LS) method of bias correction can be adopted to eliminate the biasness in the RCMs data [50-52]. The following are the equations that were used in the study to rectify the RCMs climate data.

$$T_{future,daily} = T_{GCM,daily,future} + (T_{(observed,monthly)} - T_{(GCM,observed,monthly)}) , \quad (1)$$

$$P_{future,daily} = P_{GCM,daily,future} \times \left(\frac{P_{(observed,monthly)}}{P_{(GCM,observed,monthly)}}\right) , \quad (2)$$

For the future time horizons, analysis of climate data relative to baseline data was carried out. SWAT hydrological model is being used all over the world to simulate the streamflow in very small to very large basin [53-58]. SWAT model can simulate the streamflow process in an extensive range of basins [59-63]. For each climate sequences, various hydrological simulations were applied [48]. Seasonal and average annual streamflow was evaluated relative to baseline streamflow to assess the impact on climate change. Various indicators for example high flow, mean flow, median flow, temporal shift in peaks, and low flow were analyzed relative to the baseline values to check the influence of climate change on the streamflow.

III. RESULTS

A. *Climate Change*

i. *Annual Changes*

Figure 9 shows the yearly deltas of precipitation and temperature for each progressive time horizon relative to the baseline values. The scatter graph demonstrates the changes in mean annual precipitation and changes in mean annual temperature, by using four RCM under two RCPs. By using all four RCMs (ACCESS, CNRM, MPI, and NorESM) an increase is anticipated in annual and seasonal temperature, however, a decrease is projected in annual precipitation. The rise in temperature is expected to be more with the passage of time, whereas, the variation in precipitation is expected to intensify in the forthcoming future.

Under RCP 4.5, variation in mean annual temperature (Tmax and Tmin) and precipitation is anticipated in all three time horizons the 2020s, the 2050s and the 2080s may vary from 0.11 to 1.10 °C, -15.33 to -1.64 %, 0.79 to 1.92 °C, -8.81 to -16.71 % and 1.18 to 2.74 °C, -24.32 to -1.56 %, respectively, by using four RCMs. Under RCP 8.5, variation in mean annual temperature (Tmax and Tmin) and precipitation is anticipated in all three time horizons the 2020s, 2050s, and 2080s may differ from 0.78 to 1.05 °C, -12.88 to 4 %, 1.99 to 2.71 °C, -23.16 to -20.26 % and 3.93 to 4.66 °C, -38.91 to -31.90 %, respectively, by using four RCMs (Figure 9). A wide range of variations are expected under RCP 8.5, however, a limited range of likelihoods are anticipated for temperature and precipitation under RCP 4.5.

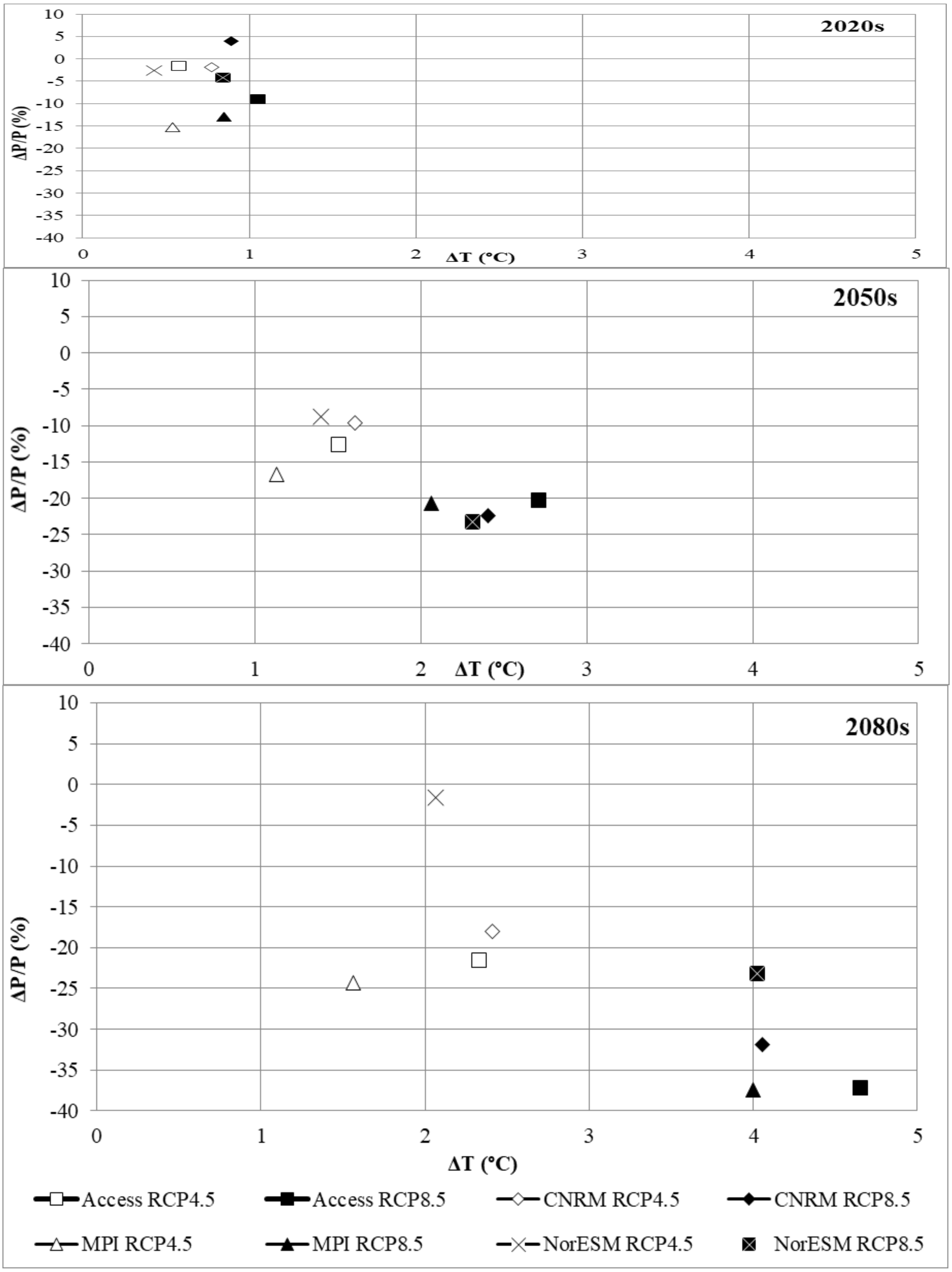


Fig. 9 : Annual Delta's of temperature and precipitation for projections of climate change.

ii. Seasonal variations

Table 7. Anticipated variations in average annual and seasonal Tmax, Tmin, and PPT in all three-time horizons.

Sr. No.	RCM	Period	RCP	Average Increase Tmax (°C)					Average Increase Tmin (°C)					Change in PPT (%)				
				DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
1	Access	2011-2040	4.5	0.29	0.18	0.32	0.50	0.33	0.61	0.70	0.97	1.03	0.83	7.73	-0.62	-19.08	2.30	-1.64
2	CNRM	2011-2040	4.5	0.15	0.34	0.71	0.61	0.45	0.66	0.87	1.52	1.34	1.10	5.55	-4.58	-6.95	0.38	-1.82
3	MPI	2011-2040	4.5	0.06	0.19	0.52	0.21	0.21	0.49	0.70	1.29	0.99	0.87	-4.32	-16.77	-28.01	-13.29	-15.33
4	NorESM	2011-2040	4.5	0.02	0.46	0.27	0.28	0.11	0.48	1.02	1.01	0.53	0.76	-6.95	1.67	-7.05	-1.50	-2.56
5	Access	2011-2040	8.5	0.93	0.89	1.22	1.16	1.05	0.76	0.88	1.33	1.24	1.05	-3.78	3.29	-47.99	-2.80	-9.05
6	CNRM	2011-2040	8.5	0.45	0.63	1.35	1.03	0.87	0.36	0.62	1.55	1.13	0.92	4.49	4.89	6.27	-2.36	4.00
7	MPI	2011-2040	8.5	0.24	0.71	1.33	0.85	0.79	0.28	0.75	1.44	1.14	0.90	-1.12	-13.41	-30.85	-7.80	-12.88
8	NorESM	2011-2040	8.5	0.52	0.94	1.21	0.43	0.78	0.41	1.04	1.36	0.81	0.91	1.42	-7.97	-2.76	-4.46	-4.16
9	Access	2041-2070	4.5	1.02	0.93	1.79	1.37	1.28	1.34	1.33	2.23	2.00	1.73	-5.60	-5.62	-55.47	11.02	-12.66
10	CNRM	2041-2070	4.5	0.76	1.10	1.77	1.51	1.29	1.17	1.56	2.64	2.28	1.92	12.54	-17.33	-28.39	-0.57	-9.65
11	MPI	2041-2070	4.5	0.09	0.62	1.62	0.80	0.79	0.65	1.21	2.44	1.63	1.48	-0.77	-6.47	-63.70	-11.94	-16.71
12	NorESM	2041-2070	4.5	0.67	1.15	1.63	0.80	1.07	1.14	1.71	2.41	1.67	1.73	0.01	-2.83	-37.39	-3.73	-8.81
13	Access	2041-2070	8.5	2.29	2.18	3.55	2.83	2.71	2.15	2.22	3.50	2.97	2.71	-7.21	-15.84	-60.66	-2.31	-20.26
14	CNRM	2041-2070	8.5	1.51	2.00	3.41	2.48	2.35	1.37	2.01	3.60	2.81	2.45	1.09	-16.94	-61.50	-26.39	-22.32
15	MPI	2041-2070	8.5	1.09	1.65	3.08	2.14	1.99	1.17	1.62	3.24	2.52	2.14	3.24	-14.04	-67.48	-19.75	-20.75
16	NorESM	2041-2070	8.5	1.59	2.04	3.39	1.89	2.23	1.56	2.13	3.57	2.28	2.39	-7.04	-19.82	-57.17	-15.71	-23.16
17	Access	2071-2100	4.5	1.68	1.67	2.86	2.31	2.13	1.86	2.11	3.28	2.84	2.53	8.64	-15.70	-80.18	-13.20	-21.57
18	CNRM	2071-2100	4.5	1.36	1.97	3.09	1.90	2.08	1.85	2.45	4.04	2.60	2.74	4.96	-23.49	-38.48	-14.57	-18.04
19	MPI	2071-2100	4.5	0.22	0.84	2.43	1.21	1.18	0.87	1.43	3.35	2.11	1.94	1.27	-19.35	-76.66	-13.69	-24.32
20	NorESM	2071-2100	4.5	1.13	1.62	2.41	1.61	1.70	1.64	2.25	3.32	2.48	2.43	11.43	9.86	-47.97	4.02	-1.56
21	Access	2071-2100	8.5	3.82	4.09	5.87	4.83	4.66	3.70	4.11	5.60	5.12	4.64	-8.75	-32.16	-92.05	-28.47	-37.22
22	CNRM	2071-2100	8.5	2.78	3.45	5.78	3.98	4.00	2.60	3.42	6.06	4.31	4.10	-6.13	-25.46	-82.53	-28.06	-31.90
23	MPI	2071-2100	8.5	2.69	3.72	5.55	3.75	3.93	2.58	3.68	5.72	4.24	4.06	9.53	-45.53	-85.72	-30.85	-37.48
24	NorESM	2071-2100	8.5	2.45	3.52	5.89	3.86	3.94	2.49	3.63	6.15	4.16	4.11	-11.16	-44.01	-78.46	-19.48	-38.91

The average monthly precipitation and temperature in Hunza Watershed are shown Figure 2. For Hunza Watershed, mean annual $T_{max,}$ $T_{min,}$ and Precipitation is -1.88°C, -12.69 °C and 977 mm, respectively. There are four seasons in the watershed: Winter(DJF), Spring(MAM), Summer(JJM) and Autumn(SON) and average seasonal Tmax, Tmin, and precipitation in Hunza Watershed is -11.3 °C, -23.40 °C and 240 mm, -3.00 °C, -13.77 °C and 410 mm, 8.56 °C, -1.13 °C and 185 mm and -1.99 °C, -12.68 °C and 141 mm, respectively. At each time horizon seasonal deltas of temperature and precipitation are displayed (Table 7). It is observed that by using four RCMs under two RCPs, less change in precipitation is observed during spring and winter as compared to change in precipitation in summer and autumn. Rainfall during Monsoon season is expected to decrease and less amount of snow is expected in winter due to probable rise in temperature.

A consistent increase in Tmax and Tmin is being observed through all the seasons. Much higher rise in temperature is foreseen in Summer. For horizon 2080s, the summer temperatures may rise by 6.15 °C under NorESM RCP 8.5. Seasonal changes in average temperature (Tmax, Tmin) and precipitation is anticipated to vary from 0.02 to 3.09 °C, 0.48 to 4.04°C and -80.18 to 12.54 %, respectively, under RCP 4.5. Precipitation and temperature (Tmin and Tmax) are anticipated to vary from -92.05 to 9.53 % from 0.28 to 6.15 °C and from 0.24 to 5.89 °C, respectively, by using four RCMs under RCP 8.5

a. Model calibration and validation

Eight parameters were found more sensitive out of twenty-seven parameters undertaken for sensitivity analysis. Studies in the past were the pivotal point for calibration to find sensitive parameters [64-69] (Table 8). SMFMN for its very low t-value and high p-value is considered to be the least sensitive parameter and SMFMX for its very high t-value and the low p-value is the parameter which influences the most.

Table 8. Parameterization using SWAT-CUP through sensitivity.

Rank	Parameter	P-test	T-test
1	SMFMX	0.000	-105.6
2	SMTMP	0.000	43.4
3	TIMP	0.000	-15.9
4	SFTMP	0.000	7.8
5	GWQMN	0.006	2.8
6	ALPHA_BF	0.114	1.58
7	SOL_AWC	0.498	-0.67
8	SMFMN	0.845	1.22

SWAT user's manual [70] can be consulted for a brief explanation of the said parameters. The optimum values of each parameter are given in Table 9.

Table 9. Final selected parameters used to calibrate the streamflow.

Parameter	Initial Range	Hunza
SOL_AWC	0 - 1	0.01
ALPHA_BF	0 - 1	0.007
SFTMP	-20-20	-0.78
SMTMP	-20-20	2.43
SMFMX	0 - 20	2.98
SMFMN	0 - 20	1.57
TIMP	0 - 1	1
GWQMN	0 - 5000	5000

After the calibration process, finalized parameters are inserted into model for simulating the streamflow. Model's estimated parameters (PBIAS, $R^{2,}$ and NSE,) are represented in Table 10 which are calculated employing the observed and simulated flow for calibration in the period 1986–1995 and for validation in the period 1996–2004 at Hunza Station. The quantitative values of PBIAS, NSE, and R^2 ranged from -11.98 %, 0.60 and 0.76 in case of calibration and values of R^2, NSE, and PBIAS, from 0.70, 0.55 and -14.09 to 14.52 % in case of validation.

Table 10. Value of calibration and validation performance indicators.

No.	Name	Calibration (1986-1995)			Validation (1996-2004)		
		R^2	NSE	PBIAS	R^2	NSE	PBIAS
1	Hunza station	0.76	0.60	-11.98	0.70	0.55	11.29

Figures 10 demonstrates the comparison between simulated and observed flows, in which several high flow peaks and low flow results were not fitted well in calibration and validation process. At Hunza station, some events peak flows and low flows observed overestimated and some events were underestimated by the model. Insufficiency of rain gauges in the catchment area might be the reason for this overestimation/underestimation of model.

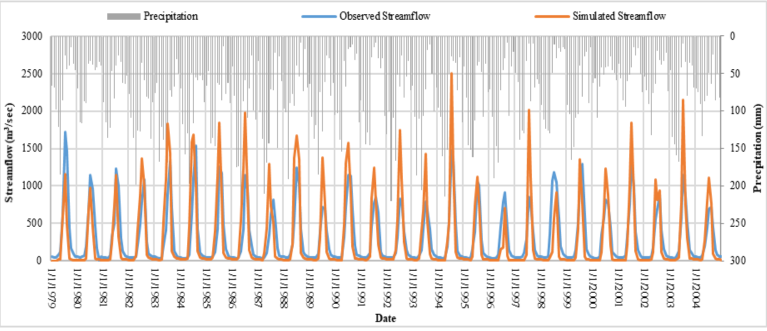


Fig. 10: Comparison between observed and simulated flows at Hunza Station.

B. Impact of climate change on streamflows

i. Annual and seasonal changes

Seasonal and average annual streamflow is illustrated in Table 11, which shows the impact of climate change. For each horizon flows and climate projection, streamflows are expressed relative to the baseline period.

Simulated streamflows values are in autumn (56.8 m^3/sec), spring (74.3 m^3/sec), summer (949.3 m^3/sec), and in winter (13.7 m^3/sec) for the baseline period (1981–2010). The changes in annual variations in streamflows are very high relative to average seasonal flows (Table 11). Changes in temperature and precipitation are the main reasons for the variations in streamflows.

Table 11. Variations in streamflow (%) using the four RCMs under the two RCPs (4.5 and 8.5).

S. No.	GCM	Period	RCP 4.5					RCP 8.5				
			DJF	MAM	JJA	SON	Annual	DJF	MAM	JJA	SON	Annual
1	Access	2020s	-37	-46	12	-9	7	-27	-26	8	-11	4
2	CNRM	2020s	-32	-21	23	2	18	-27	-6	30	-12	24
3	MPI	2020s	-47	-46	9	-27	2	-43	-29	14	-22	9
4	NorESM	2020s	-30	-9	14	-20	10	-31	8	17	-28	13
5	Access	2050s	8	-14	23	35	21	-11	25	20	38	20
6	CNRM	2050s	38	12	27	38	27	-13	63	14	-5	16
7	MPI	2050s	24	-9	15	10	14	-6	25	11	-2	11
8	NorESM	2050s	31	8	28	28	27	-10	28	16	-2	16
9	Access	2080s	36	13	14	28	15	-29	136	-14	-7	-4
10	CNRM	2080s	24	49	16	-1	17	-20	165	-7	-3	5
11	MPI	2080s	33	-17	5	-3	4	-23	158	-16	-27	-5
12	NorESM	2080s	67	46	33	47	35	-29	152	-16	-18	-4

For streamflow annual anomalies, the baseline value is the average streamflow over the reference period (1981–2010). A positive anomaly means that the simulated streamflow is more than the mean baseline streamflow, whereas, a negative anomaly means that the simulated streamflow is less than the mean baseline streamflow. Annual streamflow anomalies may vary from -40.3 to 103.3 % and -47.2 to 126.6 %, respectively, by using the four RCMs under RCPs 4.5 and 8.5 (Figures 11 and 12).

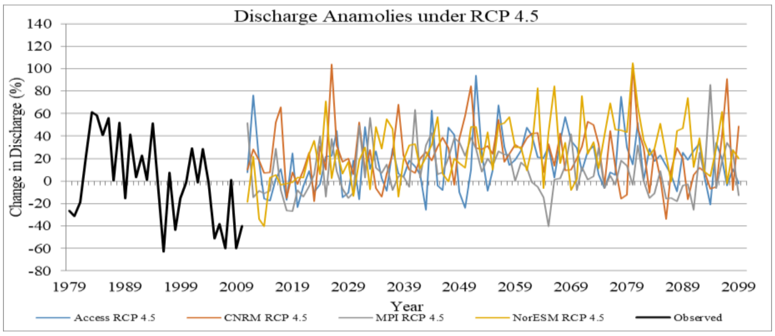


Fig. 11 : Anomalies of annual streamflow under RCP 4.5 using four RCMs.

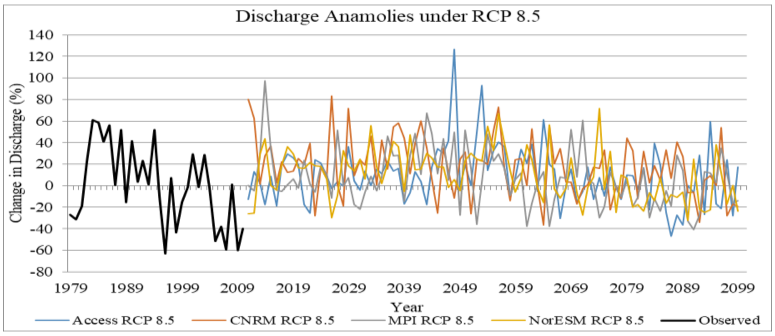


Fig. 12: Anomalies of annual streamflow under RCP 8.5 using four RCMs.

ii. Changes in low, medium, and high flows

Tables 12, 13 and 14 display the anticipated changes in low flow (Q_{95}), mean flow (Q_{50}), and high flow (Q_5), in the 2020s, the 2050s, and the 2080s relative to the baseline data and under both RCPs 4.5 and 8.5. Both low flows and high flows are projected to increase in most of the scenarios under both RCPs. Conversely, mean flows are expected to lower during 2020s and 2050s and this lowering in median flow is due to decreasing trend of future mean precipitation. This means that floods and droughts will be more frequent in future in the watershed under climate change scenarios. Hunza River Basin is expected to suffer economic losses due to the increase in extreme events along-with the decrease in median flows. However, with proper management and utilization of increase in peak as well as low flows, hydropower and food production can be increased in the study area.

Table 12. Projected variations in high flows relative to the baseline streamflow (1981–2010) using four RCMs under RCPs.

Q_5 using RCMs under RCPs	2011-2040	2041-2070	2071-2099
Access RCP4.5	1417	1547	1369
Access RCP8.5	1356	1482	1232
CNRM RCP4.5	1626	1704	1611
CNRM RCP8.5	1744	1584	1487
MPI RCP4.5	1473	1460	1413
MPI RCP8.5	1445	1355	1317
NorESM RCP4.5	1492	1710	1625
NorESM RCP8.5	1465	1417	1196
Simulated	1358 (1981-2010)		

Table 13. Projected variations in median flows relative to the baseline streamflow (1981–2010) using four RCMs under RCPs.

Q_{50} using RCMs under RCPs	2011-2040	2041-2070	2071-2099
Access RCP4.5	19.4	29.0	34.4
Access RCP8.5	20.5	26.0	29.6
CNRM RCP4.5	21.2	34.3	32.6
CNRM RCP8.5	21.0	26.2	26.3
MPI RCP4.5	15.8	31.2	31.8
MPI RCP8.5	16.9	27.6	26.2
NorESM RCP4.5	20.8	33.6	42.2
NorESM RCP8.5	20.9	27.2	25.6
Simulated	27.1 (1981-2010)		

Table 14. Projected variations in low flows relative to the baseline streamflow (1981–2010) using four RCMs under RCPs.

Q_{95} using RCMs under RCPs	2011-2040	2041-2070	2071-2099
Access RCP4.5	3.16	6.13	9.62
Access RCP8.5	3.03	4.36	1.96
CNRM RCP4.5	3.04	9.76	8.40
CNRM RCP8.5	3.38	4.94	3.53
MPI RCP4.5	2.54	7.78	7.74
MPI RCP8.5	2.48	5.04	2.40
NorESM RCP4.5	3.39	9.36	12.77
NorESM RCP8.5	2.94	5.55	2.45
Simulated	3.61 (1981-2010)		

a. Temporal shifts in stream flows including peak flows

Figures 13 and 14 display the mean monthly streamflows of the baseline period ranging from1981–2010 along-with the average monthly streamflow in the upcoming periods (the 2020s, 2050s, and 2080s) to discover the changes in magnitudes of peak flows as well as temporal variations. At the outlet of the Hunza River Basin, a definite delay/advance and growth in peak flows is anticipated for all time horizons under both RCPs. The peaks are expected to shift with the rise in future temperature along-with the changes in future precipitation and will shift from July to June in the 2050s and the 2080s. The anticipated average monthly streamflow under RCP 4.5 may differ from 11 to 1762 m^3/sec. The expected mean monthly streamflow under RCP 8.5 can change from 13 to 1606 m^3/sec by using four RCMs under both RCPs, it is seen that maximum and minimum streamflows are expected in the month of March and July.

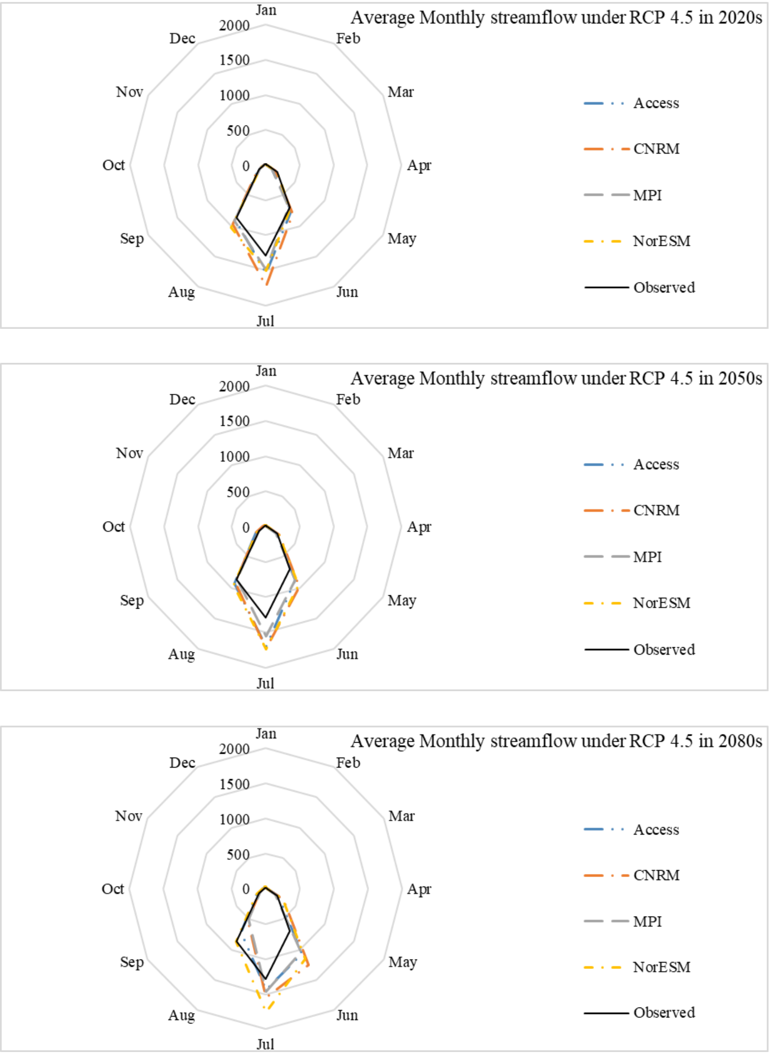
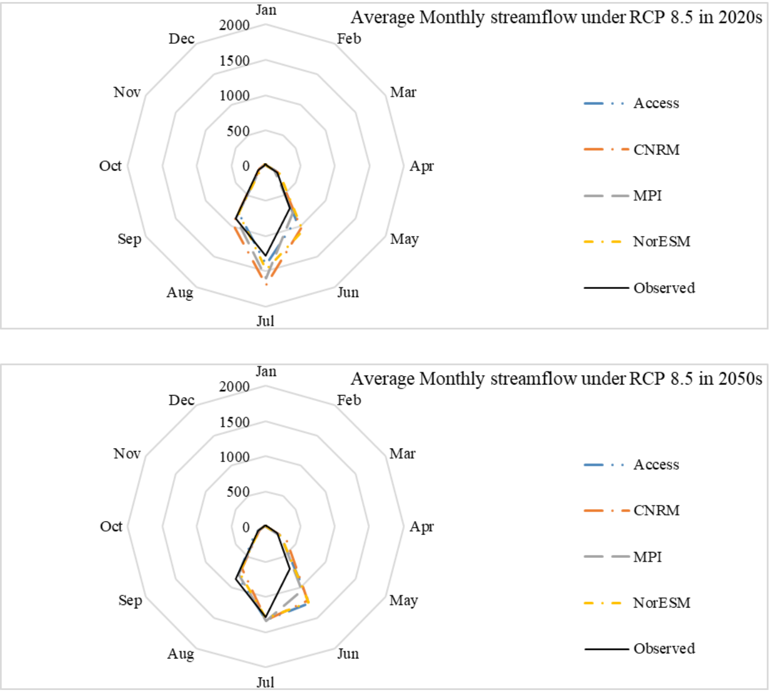


Fig. 13. : Average Monthly streamflow (m^3/sec) using the four RCMs in the 2020s, the 2050s and the 2080s under RCP 4.5



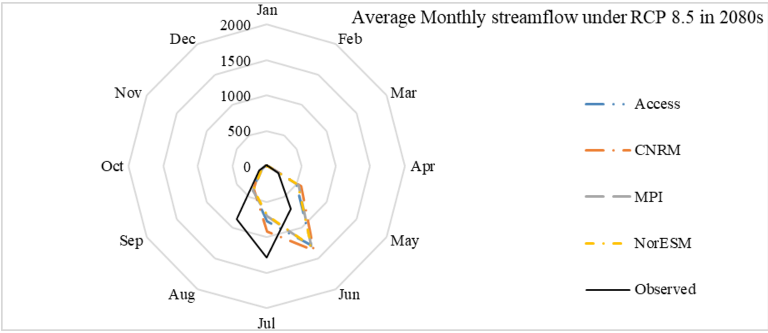


Fig. 14 : Average Monthly streamflow (m^3/sec) using the four RCMs in the 2020s, the 2050s and the 2080s under RCP 8.5

IV. CONCLUSIONS AND RECOMMENDATIONS

Pakistan is one of many countries that is prone to climate change impact on water resources. In this study, climate change impact on water resources of Hunza River Basin using RCMs under RCPs is quantified by using SWAT hydrological model to simulate streamflow after calibration (1985–1995) and validation (1996–2004) of model. To verify the performance of the model, graphical representation, coefficient of determination, Nash efficiency and Percentage deviation are the indicators that were employed. Climate data was biasally corrected and was used into hydrological model to simulate the streamflow. In this study, the projected streamflow was distributed into three future time slices (the 2020s, 2050s, and 2080s) and was analyzed with the baseline streamflow (1981–2010). Both Tmax and Tmin are expected to rise in all-time horizons using four RCMs under RCPs 4.5 and 8.5 and rise in Tmin is anticipated to be more. Temperature is expected to rise more in summer season. In winter and in spring smaller change in the precipitation is expected to occur but for autumn and summer using four RCMs, decrease in precipitation is more. Summer rainfall is anticipated to decrease whereas, in winter less amount of snowfall anticipated owing to expected increase in temperature. High and low stream flows are projected to increase and projected to happen one month early in June however, mean streamflows are projected to increase in the future time horizons.

Overall the climate of Hunza River Basin is expected to be warmer and drier relative to baseline and streamflow is expected to increase first due to increase in temperature and runoff due to snow-melt, but, lately, streamflow is projected to decline with the further increase in temperature along-with expected decrease in precipitation. Many quantitative and temporal shifts in peak flows are also expected in the basin. The results of this study will be very helpful in order to device the Basin Management Policy under climate change.

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