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Climate Change Impact on Precipitation in Arid Areas of Pakistan

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Abstract: Impact of global warming on hydrological parameters is becoming important for planners, engineers and managers in the field of water resources. The present study has forecasted the changes in precipitation for arid areas of Pakistan. Results of precipitation changes from two global climate/circulation models (GCMs) MPEH and GFCM have been compared. Double _CO_2 ($2CO_2$) experiment based on the Special Report on Emission Scenario (SRES) A2 scenario was applied.The models were calibrated and validated using existing data for 2001-2010.Thek-NN statistical downscaling and eagle point surface modelling (EPSM) techniques wereused to arrive at the results of the area of interest at three regions namely Rawalpindi, Jhelum and Attock. Results from both the downscaling schemes were compared. The forecasted results for the period 2001-2030, 2031-2060, 2061-2090 and 2091-2100 showed that there would be an increase in precipitation for all three regions. Finding of the studywere found to be in line with IPCC (Intergovernmental Panel on Climate Change) report. Current models are capable to simulate monthly rainfall pattern which also provide an insight of seasonal and annual characteristics.These increases in precipitation values in arid regions are indicative of improvements in water resources of Pakistan and will have positive impact on water resources of arid areas of the country.

Key words: Mate change · Arid areas · GCM · Statistical downscaling · EPSM

INTRODUCTION

Globally, large variance in climatic conditions is being noticed. It involves complex interactions and changing likelihoods of diverse impacts. Human activities, mainly greenhouse gases (GHGs) emissions and land use changes are the primary drivers of global climate change [1, 2]. The climate changes have significant impacts on the freshwater resources of the world [3-6]. Precipitation changes investigationsare very important especially for the regionswhere rainfall is the main source of water and crops are dependent on it. Changes in precipitation pattern due to global warming cause droughts and floods. Predictions of precipitation data for the area under study are mandatory to determine future flows in streams. The global circulation models (GCMs) and Regional Climate Models (RCMs) are commonly used for predictingprecipitation changes caused by GHG emissions. GCMs output is quiet course and provide expected precipitation covering all co-ordinates, even oceans and polar zones all over the globe for all years of specified intervals [7]. Underestimation was seen and there was difference between GCM and station precipitation gauges when the predicted and actual records were compared [7-10]. So, sophisticated techniques are required for downscaling data from GCMs onmachines with higher computational power for RCMs [11-14, 6]. The RCMs are usually used for shorter time step and are not preferred for long term climate projections [9, 15]. GCMs are successfully and

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cost effectively used for long term climate projections like in this research work wherein larger time spans and long term climate projections are made to ascertain impacts of climate changes on precipitation. To investigate climate change impacts on precipitation in arid areas of Pakistan, two GCM models with K-NN statistical downscaling technique has been used in this study as explained in the following sections.

MATERIALS AND METHODS

MPEH: MPEH is a global circulation model developed by the Max Planck Institute for Meteorology (MPI-M) which is a well-known institute for climate research [16, 17]. MPI-M develops and analyses sophisticated models of the earth system. These models simulate the hydrological cycle in the atmosphere, land and ocean. These models are important tools used to understand the behaviour of the climate globally. These models are complemented by the in-situ measurements and satellite observations. One of the models is MPEH which simulates the behaviour of and interaction among the atmosphere, the ocean, the cryosphere andthe biosphere.

GFCM: GFCM is a climate model of NOAA Geophysical Fluid Dynamics Laboratory (GFDL) [16, 17]. CM3 is the advanced version of CM2.1 and works more effectively to model and simulate the atmosphere and land. GFCM are among the family of GCM which represent the climatic system interms of computer codes that are run on supercomputers. These models are reliable due to the fact that they are based on basic physical laws and observations. Models are assessed routinely with observations of land surface, ocean and atmosphere. Organized inter-comparisons are done to check the authenticity of these models. Models simulate patterns of climate change across a range of time scales. These climate models have been proved as very important tool in understanding and simulating future climate change particularly at large scales.

Emission Scenarios: Emission scenario is a tool that determines the influence of driving forces over emission outcomes and helps to assess the associated uncertainties. The selected scenarios are used to model out the impacts and to analyse the changes in climate. IPCC developed these scenarios on the basis of increase in intensity of Carbon and Sulfur emissions considering theincome gap between developed and developing countries. Following terminologies are important in this regard.

- Storyline: It is a familyof scenarios that shows characteristics, dynamics and relationship between key driving forces.
- Scenario: A scenario is a logical quantified projection of a potential future of the storyline.
- Scenario family: It is an individual or a group of scenarios havingsimilar demographic, politico-societal, economic and technological storyline.

A scenario shows a specific quantitative interpretation of one of four storylines, listed below with their description.

A1 Storyline: It describes future world with rapid development of new and more efficient technologies, global population and fast economic growth. Confinement of regions, capacity building and increased cultural & social interactions, with a subsequent reduction in regional differences in per capita incomeare major underlying themes.

A2 Storyline: It presents preservation of local identities, slow regional fertility patterns, increasing global population and slower technological changes. Here, economic development is primarily regionally oriented. In this storyline, per capita economic growth and technological change are slower than as compared to other storylines.

B1 Storyline: It is same as A1 storyline with respect of population and economic growth but with reduction in material industry.

B2 Storyline: It explains local/regional solutions. However population is less than that in A2 storyline.
GCMs are applied to know the behaviour of atmosphere against a scenario. A scenario is open to various interpretations and reflects current understanding and knowledge about underlying uncertainties. Mostly SRES A2 is used in studies of impact of climate change. SRES A2 scenariois in order with recent emission growth [18].

Calibration and Validation of GCM: There is always need to calibrate the results of the model. GCM projections are uncertain due to errors in model structure, scenario and initial conditions. Model calibration is done by comparing model output with observed data, for a given set of assumed conditions. Nash and Sutcliff [19] used some important equations to calculate error. The following equation was modified in terms of precipitation to calibrate the results of GCM in present study.

$$NS = 1 - \frac{\sum_{i=1}^{N}[Ps(i) - Po(i)]^2}{\sum_{i=1}^{N}[Po(i) - P'o(i)]^2} \quad (1)$$

where iis time step, N is total number of steps, P_s shows simulated precipitation, P_o is observed precipitation, P_o' is mean of P_o over calibration period. NS is Nash –Sutcliffe coefficient.

Application of Downscaling: The scientists and researchers obtain projections for long- term climate evolution in different scenarios on the basis of simulations performed in GCMs. The spatial resolution (grid-spacing) of GCMs is different and does not allow direct estimation of the hydrological parameter under consideration at the station of interest. So, there is always need to develop and apply downscaling method(s). The downscaling methods can be roughly classified into two groups: (a) those using a numerical model (a regional climate model nested in a GCM) and (b) those based on a statistical model.

Researchers applied many statistical downscaling methods in past that translate global climate model output to regional station scale. These methods simple and complex as well [11, 12, 13, 14, 6]. Basic statistical properties of the data of interest are considered in simple downscaling statistics (mean and variance) whereas complex approaches consider advanced statistical properties (e.g. higher order moments or correlation structure). Limited resources and time constraints do not allow application of complex statistical methods in estimates of common water management practices Numerous uncertainties lie in the path of correct assessment of possible hydrological changes. These are uncertainties associated to climate modelling, statistical downscaling (climate model output) and natural variability of precipitation. The output of each selected climate model is an ensemble. Therefore, it should be then bedownscaled using selected method [13].

K-Nearest Neighbors (k-NN): K-NN is a well-known algorithm in pattern classification. It is simple as well as effective. Lall *et al*. [20] used local Poisson approximation of probability. The basic concept here is that the closest points (called the k nearest neighbours) have more influence on outcome of query point. In this method, a set of weights is developed by using following equation [21].

$$W(x,y)i = \frac{\exp[-D(x,y)i]}{\sum_{i=1}^{N}\exp[-D(x,y)i]} \quad (2)$$

As each station will get its own impact and value that will indicate power of influence of nearest station to selected station.However the equation given below should be satisfied in each case.

$$\sum_{i=1}^{N} W(x,y)i = 1 \quad (3)$$

Equation (3) had been modified by Statsoftinc. [22] for precipitation data.

$$P = \sum_{i=1}^{N} W(x,y)iPi \quad (4)$$

where x = Longitude, y = Latitude, P = Precipitation at unknown point, Pi = Precipitation of respective points that are nearest to query point whose precipitation is known.

The method adopted in this study considers all the four grid points that lie nearest to the query point(s). These all four points have some value of precipitation that is known. In the end weightage of each point was multiplied with precipitation of respective grid. Summation of all these products gave final precipitation at point of concern.In K-NN method, neighbour with smallest distance getsthe highest weight and neighbour with largest distance has the least weight.

Eagle Point Surface Modelling (EPSM): Various steps for EPSM are described below:

- The concerned data table is inserted in Microsoft Excel (MS-Excel) as Longitude (x) in first column, Latitude (y) in second column and Precipitation (z) in third column.
- Then a new folder is created for this study in which the respective MS-Excel file is transported and saved in .csv file extension. A blank EP-compatible AutoCAD drawing file is also saved in the same folder.
- After closing all programs, Eagle Point software is opened and a new project created (named as say MPEH-2CO2-Annual) and the respective AutoCAD file is imported there. By clicking OK, Eagle Point software opens the project in AutoCAD.
- From the tools menu, "*Surface Modeling* (SM)" is opened. Points are imported by clicking on "Prepare" and scroll down to "Import" and then "ASCII points". Data file (.csv format) is selected as (x, y, z) to import these points. All points become visible in AutoCAD by clicking zoom extents from view menu.

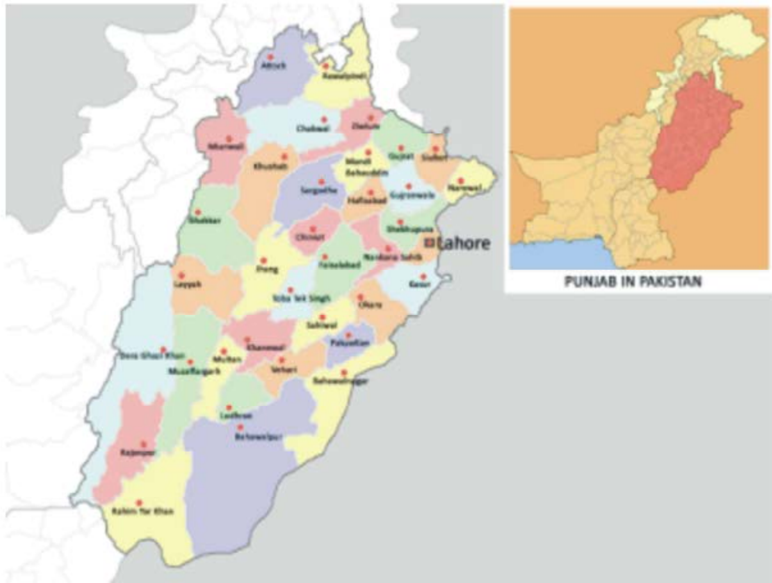

Fig. 1: Map of Pakistan highlighting Punjab and districts Rawalpindi, Attockand Jhelum

- The task of "*Triangulation*" is performed from SM menu bar. Upon its completion, a network of lines would appear with layer name "TIN". This layer could be turned off in AutoCAD to clarify the view but it forms the basis for creation of isohyets.
- Contouring in EPSM is performed by clicking on "contour – make intermediate and index contours". Here, desirable interval is given i.e. the spacing between intermediate contours is defined. This process generates isohyets (z-value pattern) on the basis of .csv data file and takes into account effects of z-values of all grid points.
- This contour drawing is superimposed on grid map of the study area.

Study Area: Pakistan (Figure 1) lies between latitude 24 and 37 degrees North and longitude 62 and 75 degrees East. The country has area of 803, 940 sq km. There are four provinces namely Punjab, Sindh, Baluchistan and Khyber PakhtoonKhawa (KPK). Pakistan has average annual precipitation of less than 240 mm (in 80% of its area). This characteristic puts it into a water-deficient country. Change in hydrological cycle is the major consequence of climate change. So a change in hydrological cycle affects the quantity and quality of regional water resources. A region is classified as arid when amount of available water is threatened to an extent that it can severely damage growth and development of plants and animal life. The focus of present study will be districts of Punjab that fall into arid zone. Punjab has thirty four(34) districts having area of 205246 sq km. Four districts of North Punjab, namely Attock, Chakwal, Rawalpindi and Jhelum, are classified as arid regions which comprise major portion of famous Pothohar region. Area of PothoharRegion is 28488.9 sq km. Pothohar Region lies between 32.5°N to 34° N latitude and from about 72° E to 74° E longitude.

RESULTS AND DISCUSSION

Calibration and Validation of Model for Precipitation: Average of observed precipitation for period of 1980-2014 has been used as base period. Data from 2001-2010 was calibrated and validated for both GCMmodels. The value of Nash –Sutcliffe coefficient was found to be varying from 0.49 to 0.98 for different seasons.

Two models GFCM and MPEH are studied for precipitation changes by the end of this century. Results have been averaged for last ten years i.e. 2091-2100 and then compared with the average of base period i.e. 1980-2014.

It is clear from tables 1 and 2 that Rawalpindi is going to receive higher rainfall as compared to Attock and Jhelum by the end of 21st century.Figures2 to 5show comparison of changes in precipitation during the simulated period (2001-2030, 2031-2060, 2061-2091 and 2091-2100) with respect to the base period (1971-2000) by applying the results of two models.

Table 1: Seasonal and annual precipitation in mm/day for 2090-2100 using GFCM model

Station	DJF	MAM	JJA	SON	Annual
Rawalpindi	2.05	2.28	8.11	2.17	3.68
Jhelum	1.59	1.61	6.33	1.58	2.84
Attock	1.91	2.30	6.01	1.76	3.06

Table 2: Seasonal and annual precipitation in mm/day for 2090-2100 using MPEH model

Station	DJF	MAM	JJA	SON	Annual
Rawalpindi	1.80	2.11	8.65	2.50	3.81
Jhelum	1.38	1.55	6.63	1.63	2.83
Attock	1.79	2.26	5.97	1.93	3.04

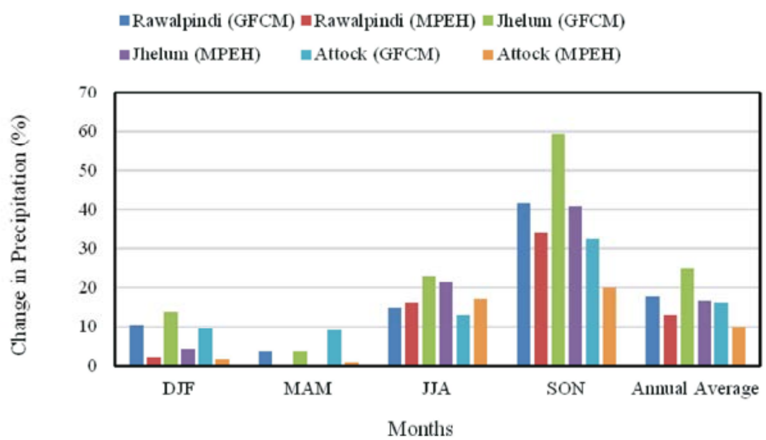

Fig. 2: Comparison of precipitation changes with respect to base period simulated by GFCM and MPEH model for time period 2001-2030

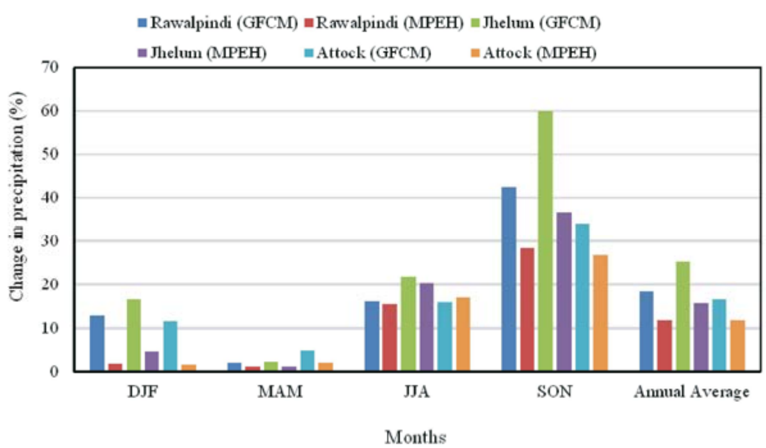

Fig. 3: Comparison of precipitation changes with respect to base period simulated by GFCM and MPEH model for time period 2031-2060

Seasonal and annual precipitation is expected to show changes. By taking average of two models for period 2091-2100, it is noticed that: Rawalpindi is expected to experience average change in precipitation of 10.25% in Winter (DJF), 7.61% in Spring (MAM), 8.12% in Summer (JJA), 28.22% in Autumn (SON) and there will be annual average increase of 13.55%. Jhelum is expected to experience average change in precipitation of 11.58% in Winter (DJF), 6.52% in Spring (MAM), 12.85 % in Summer (JJA), 40.40%in Autumn (SON) and there will be annual average increase of 17.84%.Attock is expected to experience average change in precipitation of 5.82% in Winter (DJF), 3.02% in Spring (MAM), 12.48 % in Summer (JJA), 30.05% inAutumn (SON) and there will be annual average increase of 12.84%.

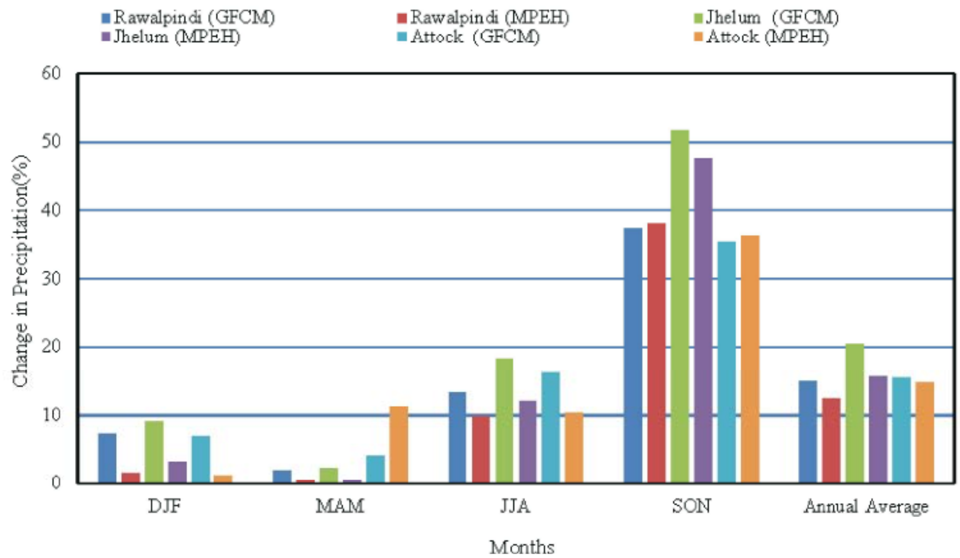

Fig. 4: Comparison of precipitation changes with respect to base period simulated by GFCM and MPEH model for time period 2061-2090

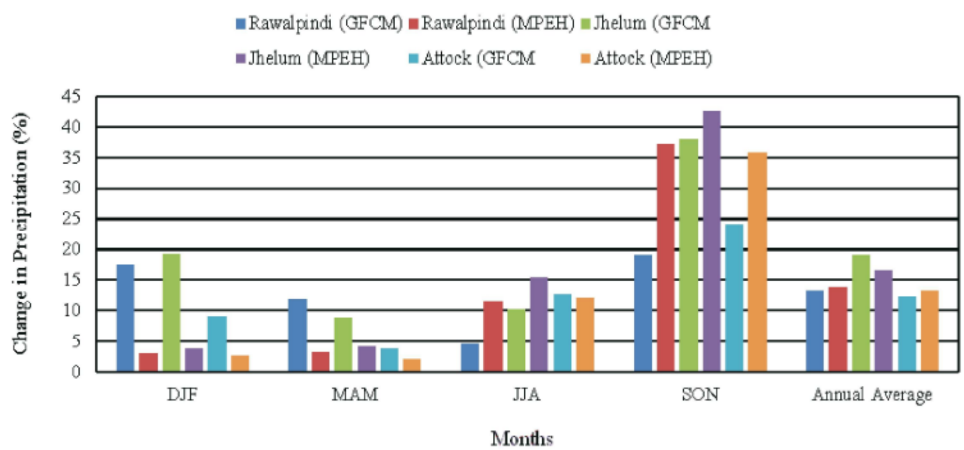

Fig. 5: Comparison of precipitation changes with respect to base period simulated by GFCM and MPEH model for time period 2091-2100.

At the scale of Arid (Pothohar) region, it can be observed, in figure 6, that during 2091-2100, the expected average precipitation change is 9.22% (average of 15.30% GFCM and 3.14% of MPEH) during winter (DJF), 5.72% (average of 8.19% GFCM and 3.24% of MPEH) in spring (MAM), 11.15% (average of 9.24% GFCM and 13.05% of MPEH) for summer (JJA), 32.89% (average of 27.03% GFCM and 38.69% of MPEH)in autumn (SON) and average annual change is estimated around 14.74% (average of 14.96% GFCM and 14.53% of MPEH).

In the above results for districts and arid region, highest percentage increase in autumn (SON) does not mean that it is going to become the heaviest rainfall time period but the highest percentage increase is due to mathematical fact that for lower values small increase results in higher percentile values.

Global warming is a phenomenon that causes increase of temperature. Due to this increase of temperature, evaporation and transportation of water vapours occurs which results in precipitation.

Regionthat is more vulnerable to warm airs experience increased precipitation because of more water molecule holding capacity of warm air. However, variation in results of two models is due to different resolutions of each model. A difference of up to 4.5 % was observed between the results of two models.

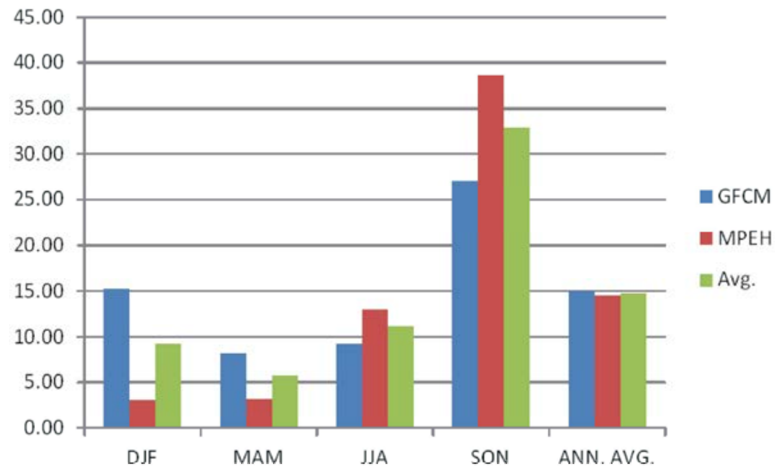

Fig. 6: Comparison of average seasonal and annual precipitation changes with respect to base period simulated by GFCM and MPEH models for time period 2091-2100 for Arid Region of Pothohar

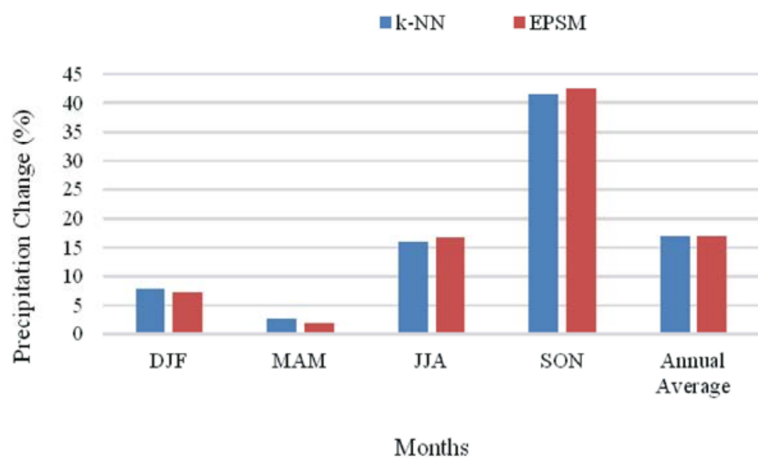

Fig. 7: Comparison of precipitation changes with respect to base period simulated by GFCM models using k-NN and EPSM downscaling techniques

GCMs have different characteristics depending upon various parameters (vertical levels, initial boundary conditions etc.) that are different for each model. Initial boundary conditions are based on observational values that are obtained from atmosphere state existing currently. A difference of about 2% was found in model results using k-NN and ESPM downscaling techniques as shown in figure 7. It is observed that results from use of different GCM models and downscaling schemes should be used very carefully. There are different sets of results with some difference among them for different combination of GCM(s) with different downscaling techniques. The present paper provides an idea of results for impact of global climate changes on precipitation of a region obtained from various techniques.

CONCLUSIONS

Following conclusions may be inferred from results and analysis of downscaled data for precipitation of study area.

- The above results of precipitation projections have been found in line with understanding of how energy and water cycles are physically related.
- Precipitation trends are simulated to remain similar to base period trends. There isincrease in precipitation for three stations under study even up to 40 % during September, October and November, which is a positive sign for the area.

- GCM differ in manner because of their assumptions and approximations taken for different physical processes. A difference of about 4.5 % in results from two models is found.
- Current models are able to simulate monthly rainfall pattern which also gives an insight of seasonal and annual characteristics.
- Method used is useful for obtaining long term projections in climate change scenario at local scale.

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