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Modeling of climate change in cold arid regions of north western Himalayas using multiple linear regression

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ABSTRACT

The present study aimed at modeling the impacts of climate change on precipitation and temperature and its trend in the context of changing climate in cold arid regions of north western Himalayas using multiple linear regression (MLR) model. The study was carried out in three different time slices *viz.,* near future (2017-2045), mid future (2046-2072) and far future (2073-2099). The study includes the calibration of the observed climate data (maximum temperature, minimum temperature and precipitation) for fourteen years (2002-2015) and the outputs of downscaled scenario A2 of the Global Climate Model (GCM) data of Hadley Centre Coupled Model, (HadCM3) was used for validation, for the future. Daily climate (maximum temperature, minimum temperature and precipitation) scenarios were generated from 1961 to 2099 under A2 defined by Intergovernmental Panel on Climate Change (IPCC). During calibration, the maximum temperature, minimum temperature and precipitation showed decreasing trend. During validation, the maximum temperature showed an increasing trend in near future (2017- 2045) and decreasing trend in mid (2046-2072) and far future (2073-2099). While as, the minimum temperature and precipitation showed an increasing trend and decreasing trend respectively, in three futuristic phases. After validation, on comparison with the measured data, the variation in maximum temperature was found -2.59 °C in near future, -3.17 °C in mid future and -3.41 °C in far future. Similarly, for minimum temperature and precipitation, the variations with observed data were found 0.91 °C and -32.2 mm, respectively in near future, 2.01 °C and -34.6 mm, respectively in mid future, 4.08 °C and -3.4 mm, respectively in far future. These changes may be found due to global warming which lead to decrease in average annual precipitation and increase in average minimum temperatures causing the melting of glaciers.

Key words: Calibration, climate change, global warming, MLR, validation.

Long-term annual or seasonal averages of climatic variables, especially temperature and precipitation, have generally been used as indicators for the assessment of climate change. Knowledge of climate extremes is important for everyday life and plays a critical role in the development and management of emergency situations, like heat waves (Satyamurty *et al.,* 2007; Toreti and Desiato, 2008). Rahimzadeh *et al.,* (2009) evidenced that the number of occurrences and intensity of low minimum temperature events around the world have decreased significantly. The reverse is true for the high maximum temperature events, but usually those trends have been weaker. IPCC (2007) presented that more extreme precipitation events have occurred over large areas of land especially in the mid and high-latitude regions. Overall, global land precipitation has increased by about 2% since the beginning of the 20th century (Jones and Hulme, 1996; Hulme *et al.,* 1998). The increase is statistically significant, though neither spatially nor temporally uniform (Karl and Knight, 1998; Doherty *et al.,* 1999). Dai *et al*., (1997) found a global long-term increase in precipitation separate from ENSO and other modes (patterns) of climate variability. The study of climate change through climate extremes is rather complex, and can be faced using a set of suitable indices describing as fully as possible the extremes of the climatic variables (Toreti and Desiato, 2008). Many studies investigated climate change and extremes on a global scale (Easterling *et al.,* 2000; Haylock *et al.,* 2006) or on a national scale (Brunetti *et al.,* 2006) but few of them made this on a local scale, using a large number of weather stations (Brunetti *et al.,* 2004; Santos and Brito, 2007).

Kaur and Kaur (2016) used the PRECIS model for downscaling of future climate data and it was found that there is a linear increase in maximum, minimum temperature and rainfall under A1B scenario in mid-century while as in end century there is rise in maximum and minimum temperature in B2 scenario which will continue at slower rate than the A1B and A2 scenarios. Chandniha and Kansal (2016) used MLR based statistical downscaling model (SDSM) to downscale the daily rainfall under both A2 and B2 scenarios in Piperiya watershed of Chhattisgarh state. Under both A2 and B2 scenarios, there has been found an increasing trend in rainfall and future rainfall under A2 scenarios was higher than B2 scenario.

This study proposes a detailed analysis of climate over the Leh region, its trend in the context of changing climate, conceptual basis for understanding changes in precipitation patterns and temperature, the observational evidence for changes and future prospects, using records of daily air temperature and precipitation in the part of cold arid region of north western Himalayas in India, through the analysis of different indices based on observational data from a weather station using MLR model. This analysis is important for the Leh region of Ladakh, since any change in climate can have large impacts on the daily life of the population and environment.

MATERIAL AND METHODS

Study area

Study area falls in the Leh region of Ladakh. The study bounded between 33° 53′ N and 34° 13′ and 77° 36′ and 77° 44′ E having geographical area 17929 ha. Leh experiences extremes type of climate where temperature ranges from 30 °C in the short summer to -35 °C in the long winter at some places. Precipitation is very low averaging around 9 to 10 cm annually. As per record maintained by the SKUAST-K, the maximum temperature of Leh is recorded 26.17 °C and minimum temperature is -13.53 °C and maximum precipitation is recorded as 45 mm (rainfall) and minimum precipitation is 4 mm (Snowfall) during the year 2015. The altitude varies between 3141 to 3961 m AMSL.

Data collection

Measured daily maximum temperature, minimum temperature and precipitation data from 2002 to 2015 were collected from the Meteorological Station Dihar, Leh. The predictors were obtained for the same area courtesy of a data portal maintained by the Canadian Climate Impacts Scenarios Group and were available from the GCM (HadCM3). The future climate data for Leh was obtained from HadCM3 (Hadley Centre Coupled Model, version 3) model, which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom. In order to reduce data volume, the global window was divided into seven smaller windows, with each window encompassing a major land area, with the land-sea boundaries defined according to the HadCM3 land-sea mask. To download HadCM3 predictors, we selected Leh on the map. The predictor variables were supplied on a grid box by grid box basis. On entering the location of our site (34° 08′ 43.43″ N 77° 34′ 03.41″ E), the correct grid box was calculated and a zip file was made available for download. Each zip file contains three directories:

NCEP_1961-2001: This directory contains 41 years of daily observed predictor data, derived from the NCEP reanalysis, normalized over the complete 1961-2001 period. These data were interpolated to the same grid as HadCM3 (2.5 latitude × 3.75 longitude) before the normalization was implemented.

H3A2a_1961-2099: This directory contains 139 years of daily GCM predictor data, derived from the HadCM3 A2experiment, normalized over the 1961-2099 period.

H3B2a_1961-2099: This directory contains 139 years of daily GCM predictor data, derived from the HadCM3 B2 experiment, normalized over the 1961-2099 period. We obtained data from second directory for Leh. The data contains daily maximum temperature, minimum temperature and rainfall from 1961 to 2099.

Data preparation

Predictors data obtained from HadCM3 are given in Table 1. A correlation analysis between the various atmospheric predictors from HadCM3 A2 model and observed database was done. The highest correlation was found between the observed data and predictors (tempas, p500, msl) were used for further analysis.

Multiple linear regression (MLR) model

Multiple linear regression describes the linear relationship with set of dependent variable Y, and k sets of independent variables X1, X2, X3……………Xk is given in below equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_k X_k + \varepsilon \ldots (1)$$

Where, Y is predict and, X_1, X_2, X_3….X_k are the predictors. "ε" is the error which is distributed normally with zero mean and variance 2. To develop the proposed model, the parameters β_1, β_2 … β_k are estimated using the training sample sets. β_0 is constant.

Data analysis and interpretation

To analyse the performance of the model, two approaches were applied *viz*., visual or graphical and statistical index methods. In this study, annual precipitation, maximum temperature and minimum temperature graphs were plotted for the calibration (2002-2015) and validation (2017-2099) periods. Results of the calibration and validation were evaluated based statistical criteria such as, Mean Square Error (MSE) or Root Mean Square Error (RMSE), Coefficient of Determination (R^2) and Absolute Average Deviation (AAD) and their equations are given below:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_{ip} - y_{ai})^2 \quad \ldots(1)$$

$$RMSE = (MSE)^{\frac{1}{2}} \quad \ldots(2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_{pi}-y_{ai})^2}{\sum_{i=1}^{n}(y_{ai}-y_m)^2} \quad \ldots(3)$$

$$AAD = \{[\sum_{i=1}^{n}(|y_{pi} - y_{ai}|/y_{ai})]/n\} \times 100$$

Where, n = No. of observations; y_{pi} = predicted value obtained; y_{ai} = actual value ; y_m = average of actual values

The future data of maximum temperature, minimum temperature and precipitation from 2017-2099 was studied in three phases *viz.,* near future (2017-2045) of 29 years, mid future (2046-2072) of 27 years and far future (2073-2099) of 27 years.

RESULTS AND DISCUSSION

The annual average maximum temperature, minimum temperature and total precipitation data from 2002-2015 was used for calibration of the model. Fig.1 shows trend of the predicted values and Table 2 shows the comparison of average observed and predicted values during 2002-2015 period. It was observed that maximum temperature, minimum temperature and precipitation showed decreasing trend with average decreasing values of 1.84 °C, -0.18 °C and 20 mm from observed values respectively. Mean square error (MSE) or Root mean square error (RMSE), Coefficient of determination (R^2) and absolute average deviation (AAD) were used for model performance evaluation and were within the permissible limits given in Table 3, suggests that the MLR model is accurate and very well be used to predict the annual maximum temperature, minimum temperature and precipitation in future periods.

The annual future data of maximum temperature, minimum temperature and precipitation from 2017-2099 was validated in three phases *viz.,* near future (2017-2045), mid future (2046-2072) and far future (2073-2099). The graphs for the respective phases of maximum temperature, minimum temperature and precipitation are given in Fig.2 to Fig.4, and the measured data (2002-2015) were compared with the predicted data for finding out the changes in future due to climate change.

From the visual analysis of Fig.2 annual maximum and minimum temperatures showed an increasing trend with average value of 13.17 °C and 1.11 °C, respectively, Table 4. While the annual precipitation presented a decreasing trend of 12.8 mm average value in the near future. It was observed that average annual maximum temperature, minimum temperature and precipitation showed a decreasing change of 2.59 °C for maximum temperature, increasing change of 0.91 °C for minimum temperature and decreasing change of 32.2 mm for precipitation in the near future (2017-2045) with the measured data (2002-2015). From annual temperature trends in near future, the highest value of average maximum temperature was observed for year 2030 in summers with value up to 14.43 °C while the average minimum temperature in winters had been observed to drop to the lowest of -0.1°C in year 2035. Similarly, for the same span, the highest and the lowest values for rainfall ranges from 15.2 mm to 10.4 mm for year 2017 and 2036, respectively.

In mid future (2046-2072), the annual maximum temperature and precipitation showed decreasing trend, while the annual minimum temperature presented an increasing trend, Fig.3. From Table 4, the average annual maximum temperature, minimum temperature and precipitation were 12.59 °C, 2.21 °C and 10.4 mm, respectively, in mid future. It was also found that average annual maximum temperature, minimum temperature and precipitation showed a decreasing change of 3.17 °C for maximum temperature, increasing change of 2.01 °C for minimum temperature and decreasing change of 34.6 mm for precipitation in the mid future (2046-2072) from the average annual observed data (2002-2015).

From the visual analysis of annual temperature trends in mid future shown in Fig.3 to the highest value of maximum average temperature was observed for year 2056 in summers with value 13.79 °C while the average minimum temperature in winters had been found to drop to 0.86°C in 2050. Similarly, for the same span, the highest and the lowest values for rainfall ranges from 14.6 mm to 6.6 mm for year 2050 and 2069, respectively.

For far future (2073-2099), the annual maximum temperature and precipitation showed decreasing trend, while the annual minimum temperature presented an increasing trend, Fig.4 similar case as found in mid future. From Table 4,

Table 1: Predictors obtained from HadCM3

S.No	Predictors	Description	S.No	Predictors	Description
1	Tempas	mean temperature at 2 m	14	p500as	500hpa geopotential height
2	Shumas	surface specific humidity	15	p5_zas	500hpa velocity
3	Rhumas	near surface relative humidity	16	p5_vas	500hpa meriodinal velocity
4	r850as	relative humidity at 850hpa	17	p5_zhas	500hpa divergence
5	r500as	relative humidity at 500 hpa	18	p5_uas	500pa zonal velocity
6	p8zhas	850 hpa divergence	19	p5_fas	500hpa air flow strength
7	p8thas	850hpa wind direction	20	p_zhas	surface divergence
8	p850as	850hpa geo-potential height	21	p_zas	surface velocity
9	p8_zas	850 hpa velocity	22	p_vas	surface meridian velocity
10	p8_vas	850 hpa meriodinal velocity	23	p_uas	surface zonal velocity
11	p8_uas	850hpa zonal velocity	24	p_thas	surface wind direction
12	p8_fas	850hpa airflow strength	25	p_fas	surface air flow strength
13	p5_thas	500hpa wind direction	26	Mslpas	men sea level pressure

Table 2: Comparison of average observed and predicted values for meteorological parameters during calibration (2002-2015)

Meteorological parameters	Observed	MLR predicted
Max. temp (^oC)	15.76	13.92
Mini. temp (^oC)	-0.12	-0.30
Precipitation (mm)	45	25

Table 3: Statistical parameters for maximum temperature, Minimum temperature and precipitation during calibration (2002-2015)

Statistical Parameters	Max. temp (^oC)	Mini. temp (^oC)	Precipitation (mm)
R^2	0.90	0.93	0.82
MSE	7.70	5.11	6.84
RMSE	2.77	2.26	3.12
AAD	7.57	3.32	3.07

Table 4: Comparison of observed and future modeled data during validation

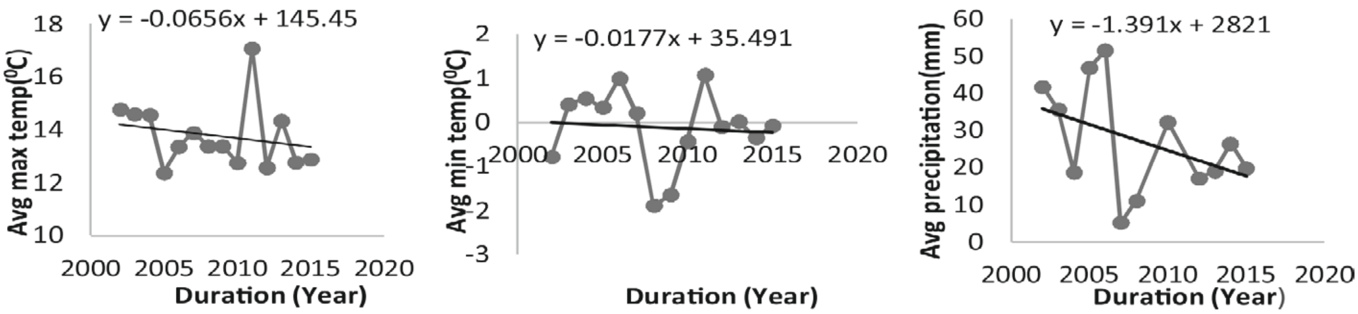
Meteorological parameters	Observed (2002-15)	MLR		
		Near future (2017-45)	Mid future (2046-72)	Far future (2073-99)
Maximum temperature (^oC)	15.7	13.1	12.5	12.3
Minimum temperature (^oC)	-0.2	1.1	2.2	4.2
Precipitation (mm/year)	45.0	12.8	10.4	11.6

the average annual value for maximum temperature, minimum temperature and precipitation were 12.35 ^oC, 4.28 ^oC and 11.6 mm, respectively, in far future. It was also found that average annual maximum temperature, minimum temperature and precipitation showed a decreasing change of 3.41 ^oC for maximum temperature, increasing change of 4.08 ^oC for minimum temperature and decreasing change of 33.4 mm for precipitation in the far future (2046-2072) from the average annual observed data (2002-2015).

From annual temperature trends in far future, highest value of maximum average temperature was observed for year 2083 in summers with value of 13.87 ^oC, while average minimum temperature in winters was found to drop to the lowest of 1.8 ^oC, in 2081. Similarly, for the same span, highest and lowest values for rainfall range from 11.4 mm to 5.4 mm for year 2074 and 2097, respectively.

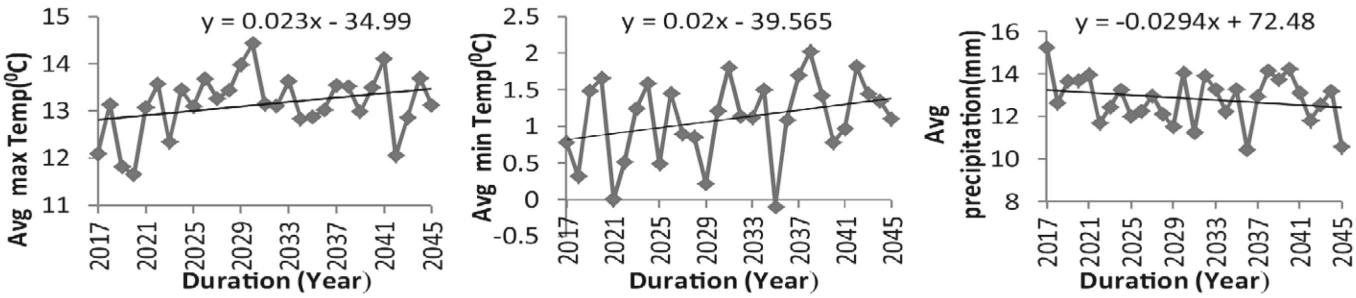
CONCLUSION

In this study, MLR model was carried out to predict the impact of climate change on precipitation and temperature in



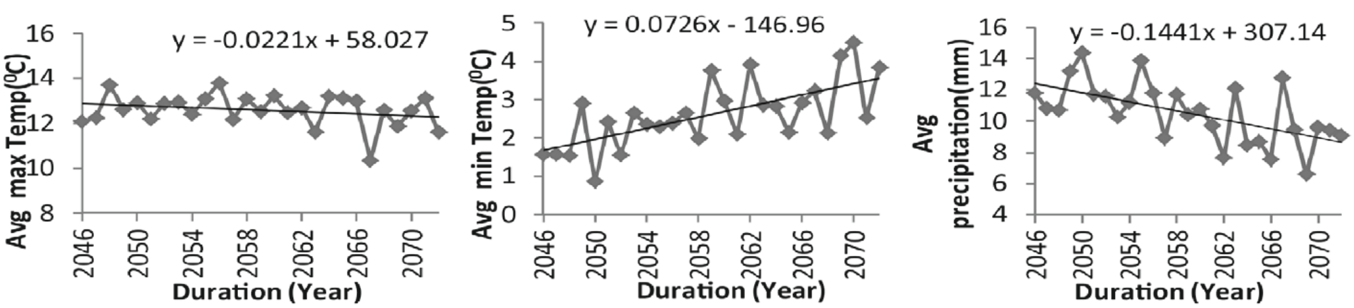
(a) (b) (c)

Fig. 1: Trend of (a) average maximum temperature (b) average minimum temperature and (c) rainfall during calibration (2002- 2015)



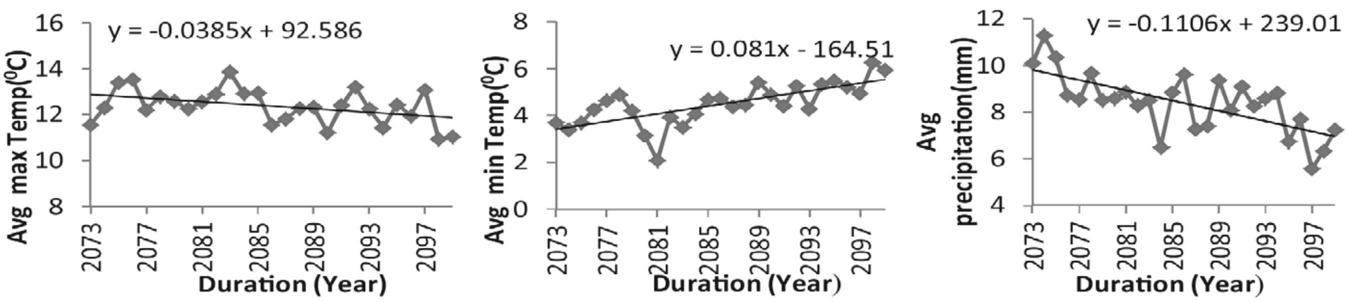
(a) (b) (c)

Fig. 2: Trend of (a) maximum temperature (b) minimum temperature and (c) precipitation in near future (2017-2045



(a) (b) (c)

Fig. 3: Trend of (a) maximum temperature (b) minimum temperature and (c) precipitation in mid future (2046-2072)



(a) (b) (c)

Fig. 4: Trend of (a) maximum temperature (b) minimum temperature and (c) precipitation in far future (2073-2099)

three futuristic phases *i.e.,* near future, mid future and far future over the cold-arid regions of north western Himalayas with Leh, as reference. The maximum temperature showed an increasing trend in near future (2017- 2045) and decreasing trend in mid (2046-2072) and far future (2073-2099).The minimum temperature and precipitation showed an increasing trend and decreasing trend respectively, in three futuristic phases. In far future (2046-2072), decreasing change of 3.41 ^{o}C for maximum temperature, increasing change of 4.08 ^{o}C for minimum temperature and decreasing change of 33.4 mm for precipitation was found on comparison with the average annual observed data (2002-2015).

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