

Figure 3: Comparing observed and downscaled values of precipitation for all three stations during validation for CGCM3 and HadCM3 models

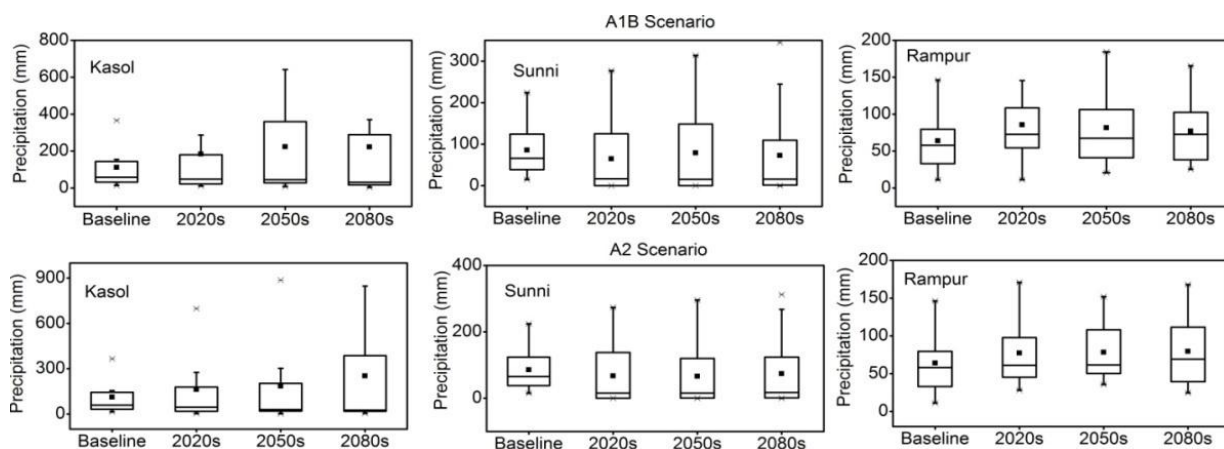


Figure 4: Box plots results from SDSM based downscaling model for the projected precipitation (CGCM3 model). The horizontal line in the middle of the box represents median value while darkened square represents mean value of precipitation data

5.2. Spatial and Temporal Patterns of Downscaled Precipitation for Future Periods

The calibrated SDSM model is used to downscale and generate future scenarios of precipitation from predictors of CGCM3 (SRES A2 and A1B) and HadCM3 (SRES A2 and B2) models in the study region. The pattern of downscaled precipitation is investigated for future periods with a box plot. For this study, the

future period is grouped into three time slices; 2020's (2011–2040), 2050's (2041–2070) and 2080's (2071–2099) and each corresponds to span of 30 year periods respectively. The downscaled precipitation is compared with baseline precipitation (1970-2000) to observe change in patterns of precipitation.

The projected precipitation for the future periods (2020's, 2050's and 2080's) has been shown in Figure 4 for the CGCM3 model.

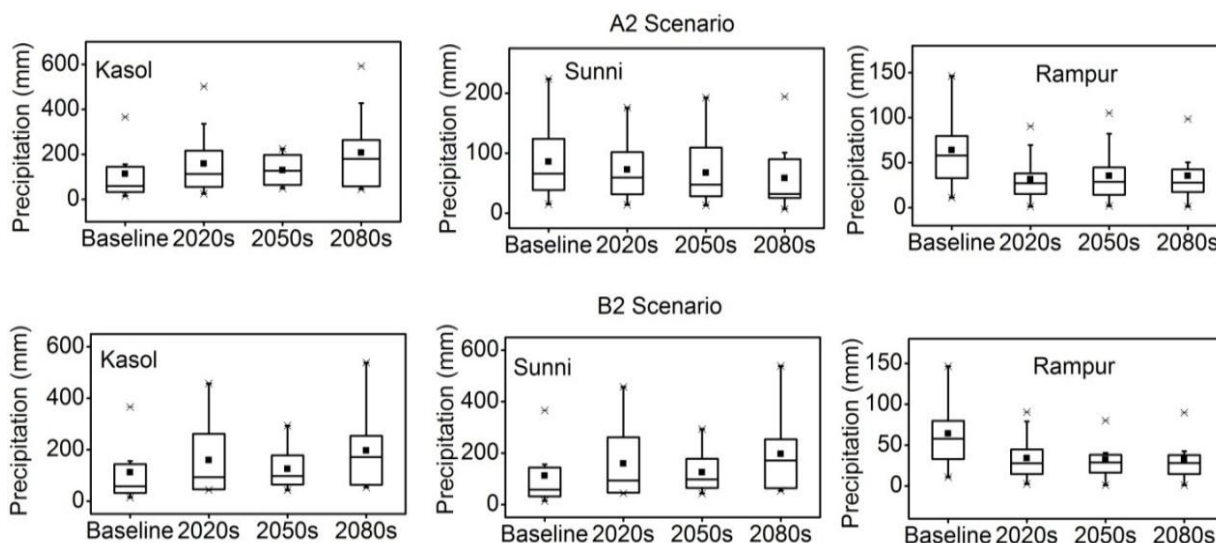


Figure 5: Box plots results from SDSM based downscaling model for the projected precipitation (HadCM3 model). The horizontal line in the middle of the box represents median value while darkened square represents mean value of precipitation data

The increase in future precipitation has been observed at Kasol and Rampur while decrease has been found at Sunni for SRES A2 and SRES A1B scenarios. An overall increase of 5.67%, 8.52% and 18.25% has been computed in mean annual precipitation in the study area under A1B scenario during 2020's, 2050's and 2080's whereas it is 9.21%, 11.23% and 13.91% under A2 scenario respectively. The increase in projected precipitation is higher for A2 scenario as compared to A1B scenario.

The results obtained from HadCM3 model is shown in Figure 5. The decline in amount of simulated precipitation has been found at Sunni and Rampur whereas increase at Kasol for SRES A2 and SRES B2 scenarios. The net change in amount of mean annual precipitation has been computed over study area under SRES A2 and SRES B2 scenarios. The results show increase in magnitude of precipitation under A2 and B2 scenarios for 2080's and decrease for 2050's respectively. This has been found 5.24% under A2 scenario and 4.57% under B2 scenario for

2080's and 3.77% under A2 and 4.08% under B2 for 2050's. For 2020's, no change in mean annual precipitation has been noticed under A2 whereas it is 0.92% under B2 scenario. The poor results obtained during calibration and validation suggests that predictors of HadCM3 model are not well simulated. Further, these are unable to capture regional climate dynamics and hence, poorly projected by SDSM model as compared to CGCM3 model.

The seasonal patterns of projected precipitation have been studied and presented in Table 5 for CGCM3 model. The large increase in projected precipitation has been found at Kasol and significant decrease at Sunni during JJA (June, July, August) periods. The unexpected results have been observed at Rampur. The increase in projected precipitation has been shown during JJA periods for A1B emission scenario and decrease for A2 scenario accordingly. The model predicts increase in projected precipitation under SON (September, October, November) periods for all three stations.

Table 5: Change in projected precipitation during different seasons for CGCM3 model

Station	Season	Change in Precipitation (cm)					
		SRES A2 Scenario			SRES A1B Scenario		
		2020's	2050's	2080's	2020's	2050's	2080's
Kasol	DJF	-0.76	-1.95	-2.74	0.41	1.42	2.14
	MAM	-2.48	-2.79	-2.69	1.25	2.24	2.70
	JJA	19.15	28.75	49.24	25.90	29.90	41.68
	SON	4.13	5.01	12.24	4.78	18.54	7.24
Sunni	DJF	1.27	0.06	0.38	0.50	2.13	0.50
	MAM	-3.40	-3.36	-3.39	3.52	3.56	3.43
	JJA	-10.73	-10.46	-8.42	10.07	7.85	9.26
	SON	5.37	5.97	6.63	5.33	6.50	7.98
Rampur	DJF	1.42	0.44	7.26	1.29	1.74	1.22
	MAM	3.63	8.92	4.40	0.20	1.20	1.81
	JJA	-0.18	-6.24	-5.83	5.29	4.23	2.17
	SON	0.47	2.60	0.41	1.91	2.27	3.60

Table 6: Change in projected precipitation during different seasons for HadCM3 model

Station	Season	Change in Precipitation (cm)					
		SRES A2 Scenario			SRES B2 Scenario		
		2020's	2050's	2080's	2020's	2050's	2080's
Kasol	DJF	19.37	5.11	37.75	18.72	2.39	36.73
	MAM	22.13	6.22	9.99	24.04	6.59	8.78
	JJA	-23.99	-6.99	-23.52	-24.52	-5.84	-23.06
	SON	1.03	2.48	13.78	0.57	2.13	11.38
Sunni	DJF	-0.023	-2.02	-3.37	-0.65	-1.51	-2.23
	MAM	4.78	3.22	0.89	4.55	2.78	2.61
	JJA	-7.98	-6.86	-6.62	-6.57	-5.14	-6.34
	SON	-1.89	-1.60	-1.87	-1.83	-1.77	-1.80
Rampur	DJF	-3.19	0.20	-2.91	-3.20	-3.01	-3.16
	MAM	-2.30	-1.94	-2.21	-1.66	-2.19	-2.36
	JJA	-5.02	-4.32	-4.12	-4.85	-5.14	-4.92
	SON	-2.41	-2.13	-2.12	-2.32	-2.23	-2.20

On contrary, the projected precipitation obtained from HadCM3 model (Table 6) show significant differences in results that are obtained from CGCM3 model. The amount of precipitation is reduced significantly during JJA periods at Kasol. The decrease in projected precipitation has been observed for future periods at Sunni and Rampur respectively.

6. CONCLUSION

In the present paper, a multiple regression based statistical downscaling tool popularly known as SDSM 4.2 is successfully applied to downscale and generate future scenarios of precipitation from predictors of CGCM3 and HadCM3 models in a part of North-Western

(N-W) Himalayan region, India. The change in projected precipitation has been studied for the time periods; 2020's, 2050's and 2080's for SRES A2 and A1B scenarios (CGCM3 model) and for SRES A2 and B2 scenarios respectively. The seasonal patterns of precipitation are also examined and changes with respect to baseline period are shown.

The results of precipitation downscaling using SDSM are found to be poor for HadCM3 model as compared to CGCM3 model. The results obtained from CGCM3 model predict an overall increase in precipitation while decrease in precipitation is predicted by HadCM3 model for the future periods in the region. Based on the analysis of results, CGCM3 model has been found better for simulation of precipitation in comparison to HadCM3 model.

APPENDIX: 1

Abbreviations used in Table 1

Predictors	Description
msl	Mean sea level pressure
p_f	Surface air flow strength
p_v	Surface meridional velocity
p_z	Surface vorticity
p_th	Surface wind direction
pzh	Surface divergence
p5_f	500 hpa airflow strength
p5_u	500 hpa zonal velocity
p5_v	500 hpa meridional velocity
Predictors	Description
p500	500 hpa geopotential height
p5zh	500hpa divergence
p8_z	850 hpa vorticity
p8_th	850 hpa wind direction
s850	Relative/Specific humidity at 850 hpa
p8zh	850 hpa divergence
rhum	Near surface relative humidity
shum	Surface specific humidity
temp	Mean temperature at 2 m

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