Article

Impacts of Climate Change on the Hydrometeorological Characteristics of the Soan River Basin, Pakistan

Muhammad Usman [1,*], Christopher E. Ndehedehe [2,3], Rodrigo Manzanas [4], Burhan Ahmad [1] and Oluwafemi E. Adeyeri [5,6]

[1] Research and Development Division, Pakistan Meteorological Department, Pitras Bukhari Road, H-8/2, Islamabad, 44000, Pakistan; burhanahmadkhan@gmail.com
[2] Australian Rivers Institute, Griffith University, Nathan, Queensland 4111, Australia; c.ndehedehe@griffith.edu.au
[3] School of Environment & Science, Griffith University, Nathan, Queensland 4111, Australia
[4] Meteorology Group, Dpto. de Matemática Aplicada y Ciencias de la Computación, Universidad de Cantabria, 39005 Santander, Spain; rodrigo.manzanas@unican.es
[5] Department of Meteorology and Climate Science, Federal University of Technology, Akure, Nigeria; eoadeyeri@futa.edu.ng
[6] Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Campus Alpine, Garmisch-Partenkirchen, Germany
* Correspondence: usman666.m@gmail.com

Table S1. Model name, modeling group, and country of the GCMs used.

Serial no	Model name	Modelling group	Country
1	ACCESS 1.0	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology	Australia
2	BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration (BCC)	China
3	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University (GCESS)	China
4	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCMA)	Canada
5	CCSM4	NCAR Community Climate System Model, (CCSM)	USA
6	CESM1-BGC	Community Earth System Model Contributors	USA
7	CNRM-CM5	Centre National de Recherches Météorologiques Centre Européen de Recherche et Formation Avancée en CalculScientifique	France

8	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization in collaboration with QCCCE (CSIRO-QCCCCE)	Australia
9	GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	USA
10	GFDL-ESM2G		
11	GFDL-ESM2M		
12	INMCM4	Institute for Numerical Mathematics (INM)	Russia
13	IPSL-CM5A-LR	Institut Pierre-Simon Laplace (IPSL)	France
14	IPSL-CM5A-MR		
15	MIROC5	(The University of Tokyo), and National Institute for Environmental Studies (MIROC)	Japan
16	MIROC-ESM		
17	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute	Japan
18	MPI-ESM-LR	Max-Planck-Institut für Meteorologie (MPI-M)	Germany
19	MPI-ESM-MR		
20	MRI-CGCM3	Meteorological Research Institute (MRI)	Germany
21	NorESM1-M	Norwegian Climate Centre (NCC)	Norway

Table S2. Precipitation values in mm at daily temporal scale and their differences to observed precipitation for the period 1980 to 2004 for Chirah sub catchment. *>1mm P days* = Average number of days in a year with precipitation > 1 mm; Ave. = average daily precipitation; Max. = maximum daily precipitation; SD = standard deviation. Differences are calculated by division (SDsim / SDgauge) for SD and subtraction for the other parameters. Where SDsim and SDgauge are the standard deviations of the climate models' and gauge precipitations, respectively.

	Absolute values				Difference w.r.t observed values			
	Avg	Max	SD	>1mm P days	Avg	Max	SD	>1mm P days

Obs	4.85	255.00	13.56	100.04				
NEX-GDDP GCMs								
ACCESS1-0	3.13	236.98	10.23	103.68	-1.72	-18.02	0.75	3.64
bcc-csm1-1	3.00	170.99	8.21	132.52	-1.85	-84.01	0.61	32.48
BNU-ESM	3.21	233.27	8.81	141.92	-1.64	-21.73	0.65	41.88
CanESM2	2.97	113.13	7.29	139.04	-1.88	-141.87	0.54	39.00
CCSM4	3.40	229.04	12.09	84.68	-1.45	-25.96	0.89	-15.36
CESM1-BGC	3.08	285.72	11.22	85.76	-1.77	30.72	0.83	-14.28
CNRM-CM5	3.27	190.94	10.11	106.92	-1.58	-64.06	0.75	6.88
CSIRO-Mk3-6-0	2.49	194.73	8.57	79.76	-2.36	-60.27	0.63	-20.28
GFDL-CM3	3.08	250.27	9.28	116.28	-1.77	-4.73	0.68	16.24
GFDL-ESM2G	3.12	112.11	7.84	133.80	-1.73	-142.89	0.58	33.76
GFDL-ESM2M	3.18	134.01	8.18	135.00	-1.67	-120.99	0.60	34.96
inmcm4	2.99	214.57	9.70	100.48	-1.86	-40.43	0.72	0.44
IPSL-CM5A-LR	3.19	150.46	8.70	124.96	-1.66	-104.54	0.64	24.92
IPSL-CM5A-MR	3.05	202.12	9.22	107.92	-1.80	-52.88	0.68	7.88
MIROC5	3.24	213.82	10.44	105.48	-1.61	-41.18	0.77	5.44
MIROC-ESM	2.95	200.73	7.67	134.48	-1.90	-54.27	0.57	34.44
MIROC-ESM-CHEM	3.01	166.01	7.78	137.12	-1.84	-88.99	0.57	37.08
MPI-ESM-LR	3.05	200.72	9.30	114.96	-1.80	-54.28	0.69	14.92
MPI-ESM-MR	3.09	304.17	10.09	107.76	-1.76	49.17	0.74	7.72
MRI-CGCM3	3.35	352.76	11.55	102.56	-1.50	97.76	0.85	2.52
NorESM1-M	3.09	367.42	9.64	114.44	-1.76	112.42	0.71	14.40

Table S3. Precipitation values in mm at daily temporal scale and their differences to observed precipitation for the period 1980 to 2004 for Dhoke Pathan sub catchment. *>1mm P days* = Average number of days in a year with precipitation > 1 mm; Ave. = average daily precipitation; Max. = maximum daily precipitation; SD = standard deviation. Differences are calculated by division (SDsim / SDgauge) for SD and subtraction for the other

parameters. Where SDsim and SDgauge are the standard deviations of the climate models' and gauge precipitations, respectively.

	Absolute values				Difference w.r.t observed values			
	Avg	Max	SD	>1mm P days	Avg	Max	SD	>1mm P days
Obs	4.10	216.90	11.20	104.28				
NEX-GDDP GCMs								
ACCESS1-0	2.99	242.69	9.77	100.64	-1.11	25.79	0.87	-3.64
bcc-csm1-1	2.89	166.72	7.91	130.48	-1.21	-50.18	0.71	26.20
BNU-ESM	3.11	218.31	8.50	139.68	-0.99	1.41	0.76	35.40
CanESM2	2.86	110.62	7.01	136.12	-1.24	-106.28	0.63	31.84
CCSM4	3.24	229.33	11.43	84.84	-0.86	12.43	1.02	-19.44
CESM1-BGC	2.96	290.92	10.66	85.16	-1.14	74.02	0.95	-19.12
CNRM-CM5	3.14	175.82	9.64	104.32	-0.96	-41.08	0.86	0.04
CSIRO-Mk3-6-0	2.33	171.16	8.07	75.4	-1.77	-45.74	0.72	-28.88
GFDL-CM3	3.00	220.31	8.94	114.84	-1.10	3.41	0.80	10.56
GFDL-ESM2G	3.04	115.66	7.72	132.48	-1.06	-101.24	0.69	28.20
GFDL-ESM2M	3.08	137.91	7.95	133.44	-1.02	-78.99	0.71	29.16
inmcm4	2.90	212.45	9.42	100.28	-1.20	-4.45	0.84	-4.00
IPSL-CM5A-LR	3.07	149.56	8.51	120.56	-1.03	-67.34	0.76	16.28
IPSL-CM5A-MR	2.93	189.84	8.85	106.12	-1.17	-27.06	0.79	1.84
MIROC5	3.13	207.37	10.02	102.68	-0.97	-9.53	0.89	-1.60
MIROC-ESM	2.84	205.13	7.45	132.16	-1.26	-11.77	0.66	27.88
MIROC-ESM-CHEM	2.93	151.37	7.61	134.72	-1.17	-65.53	0.68	30.44
MPI-ESM-LR	2.90	198.50	8.79	112.04	-1.20	-18.40	0.78	7.76
MPI-ESM-MR	2.93	203.99	9.34	105.68	-1.17	-12.91	0.83	1.40
MRI-CGCM3	3.20	257.34	10.79	100.48	-0.90	40.44	0.96	-3.80
NorESM1-M	2.97	313.94	9.11	111.08	-1.13	97.04	0.81	6.80

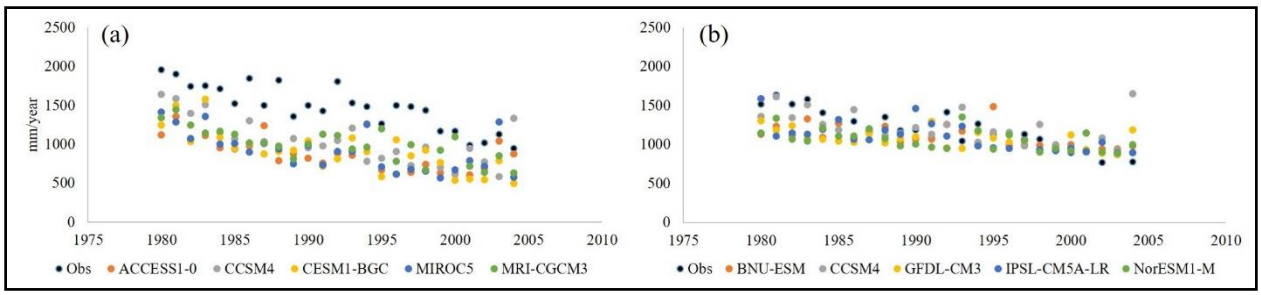

Figure S1. Interannual variability of streamflow in the historic period (1980-2004) characterized by selected GCMs for both catchments (a) Chirah and (b) Dhoke Pathan.

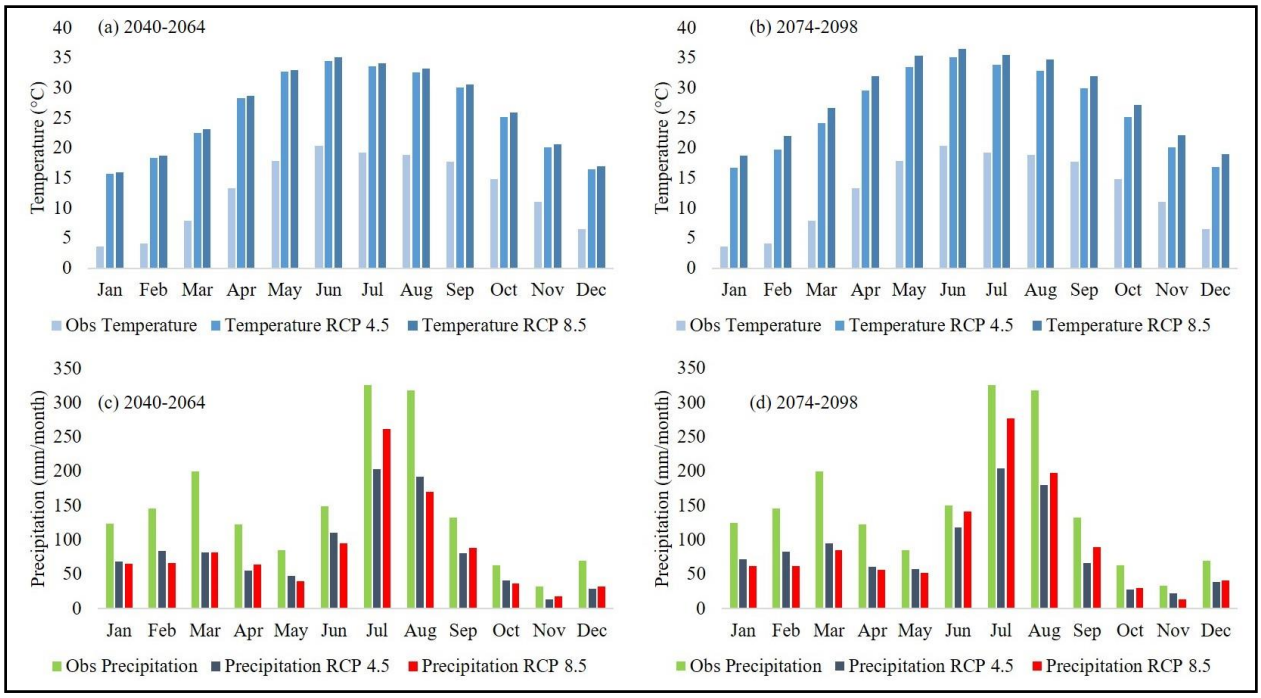

Figure S2. Average monthly temperature and precipitation projected with 5 models ensemble in the Chirah sub catchment under the RCP 4.5 and RCP 8.5 emission scenarios for two future periods. (a) temperature for (2040-2064), (b) temperature for (2074-2098), (c) precipitation for (2040-2064), d (precipitation for 2074-2098).

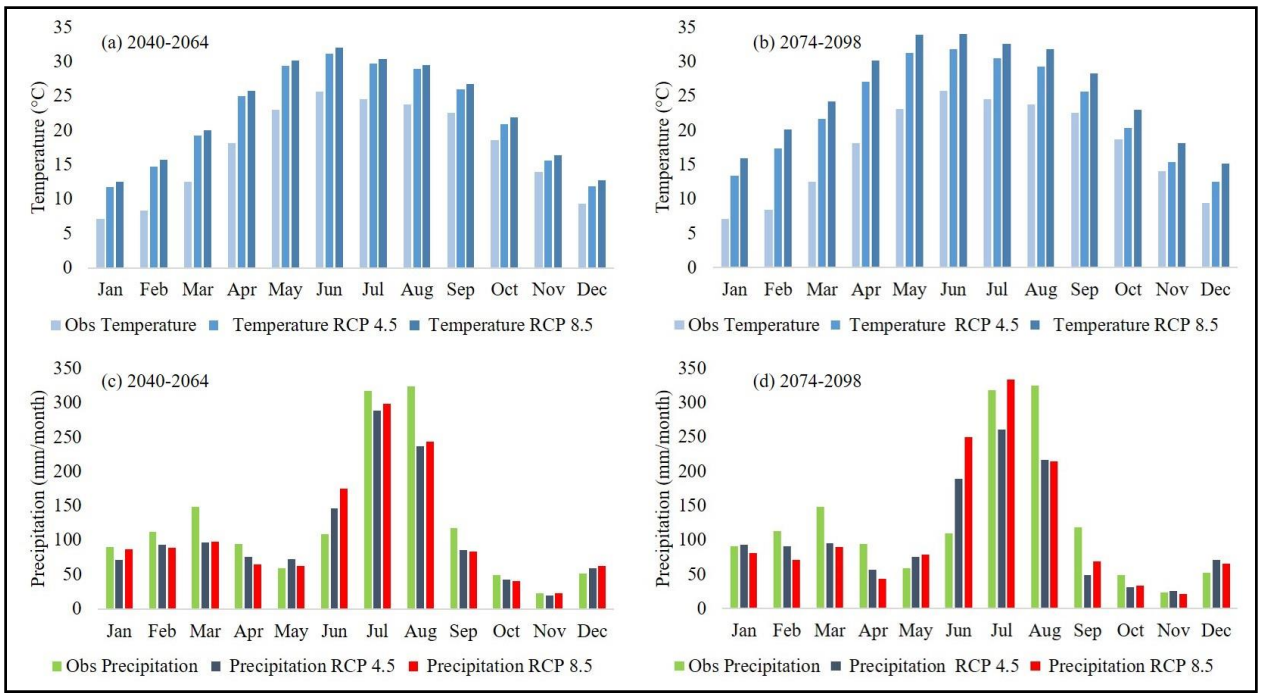

Figure S3. Average monthly temperature and precipitation projected with 5 models ensemble in the Dhoke Pathan sub catchment under the RCP 4.5 and RCP 8.5 emission scenarios for two future periods. (a) temperature for (2040-2064), (b) temperature for (2074-2098), (c) precipitation for (2040-2064), d (precipitation for 2074-2098).

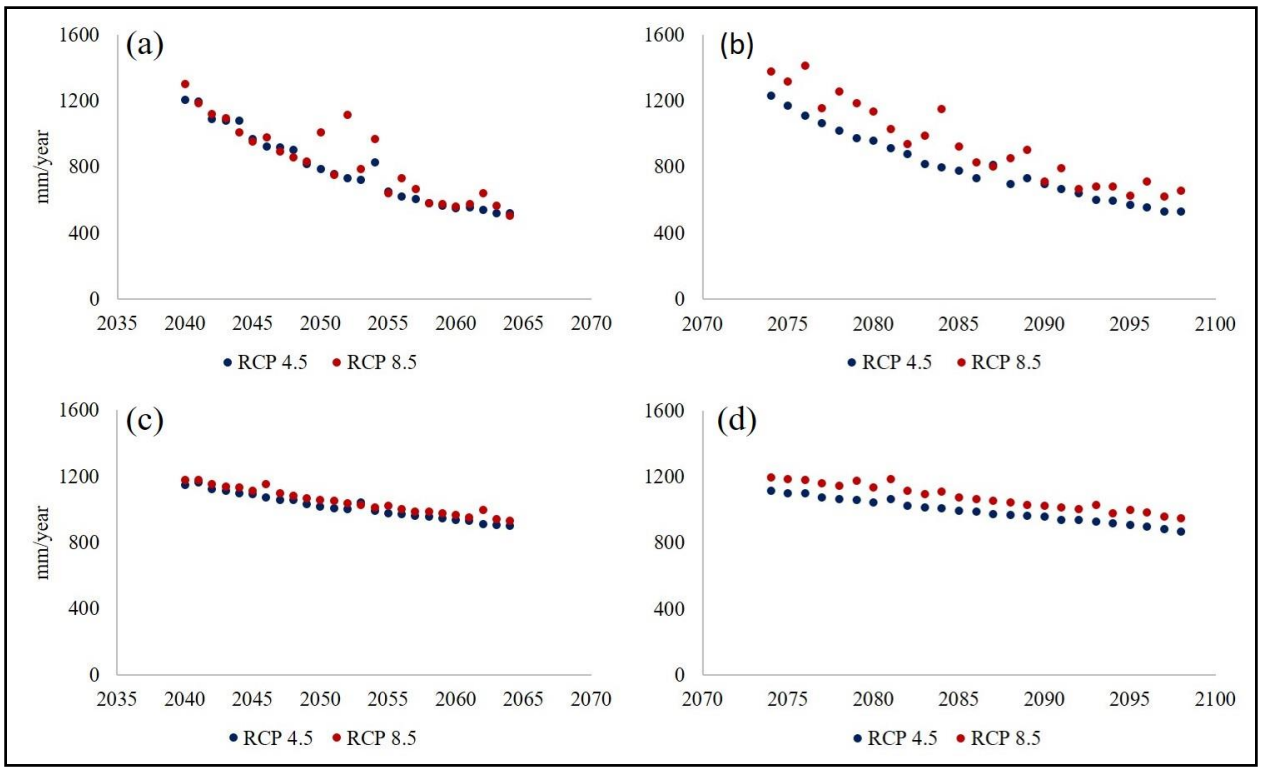

Figure S4. Interannual variability of streamflow in the future periods (2040-2064; (a) Chirah sub catchment and (c) Dhoke Pathan sub catchment and 2074-2098; (b) Chirah sub catchment and (d) Dhoke Pathan sub catchment) characterized by ensemble of selected GCMs.