Supplementary Material: Assessment of Climate Change Impact on Reservoir Inflows Using Multi Climate-Models under RCPs—A Case of Mangla Dam, in Pakistan

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Supplementary Material A: Selection of GCMs

GCMs were selected based on vintage, resolution, validity and representativeness of results. The combination of GCMs can be used even though the selected GCMs may not necessarily be the best models for the area [1].

Performance Parameters

Mostly the following statistical parameters are used for the comparison of data from two or more different sources [2]. The best GCM was selected on the basis of the following criteria described by [3]. Correlation coefficient (R^2), standard deviation (SD), Root mean square error (RMSE) and graphical presentation are the parameters to check the performance of GCMs.

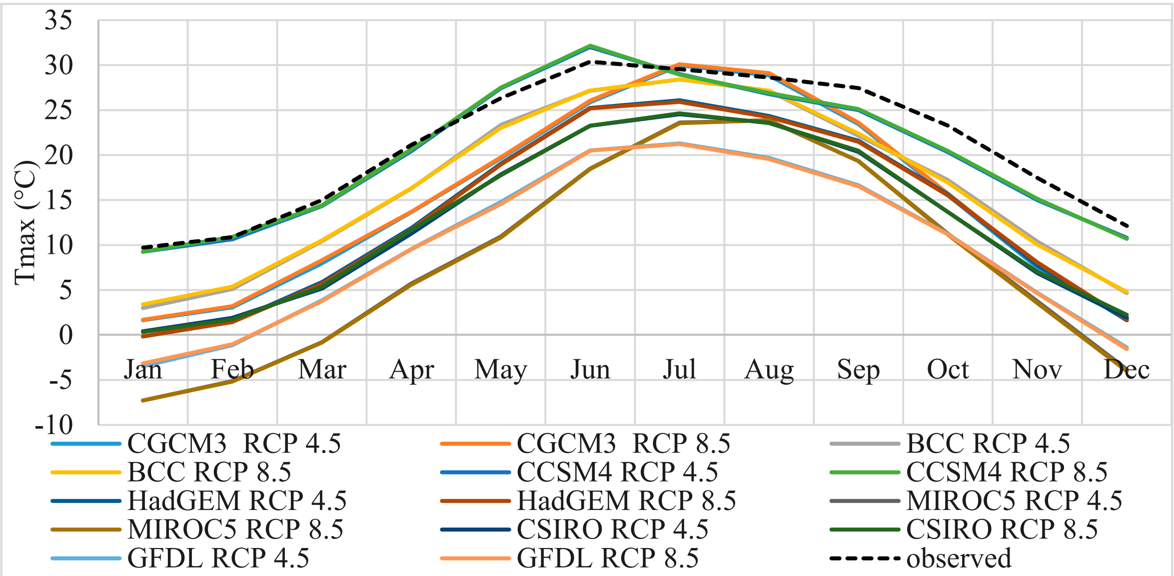


Figure S1. *Cont.*

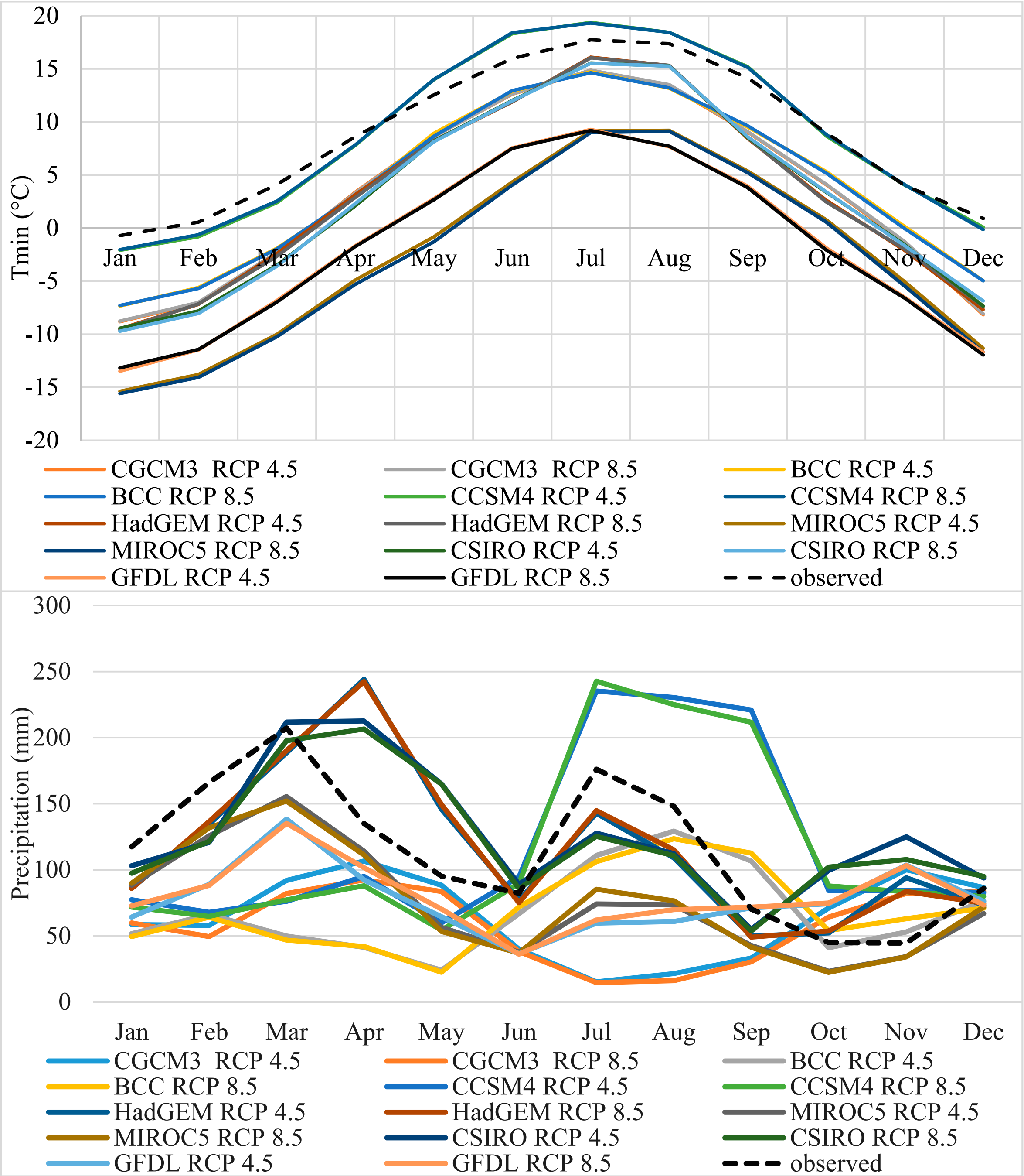


Figure S1. Mean monthly, Tmax, Tmin and precipitation using different GCMs against the observed data in the Jhelum River basin (Raw data for the period of 1981–2010).

Table S1. R^2, RMSE, and SD calculated from observed and GCMs raw data for Tmax, Tmin and precipitation for the period of 1981–2010.

	Maximum Temperature			**Minimum Temperature**			**Precipitation**		
	R^2	**RMSE (°C)**	**SD (°C)**	**R^2**	**RMSE (°C)**	**SD (°C)**	**R^2**	**RMSE (mm)**	**SD (mm)**
Observed	1.00	0.0	7.9	1.00	0.0	6.8	1.00	0.0	6.5
CGCM3 RCP 4.5	0.78	8.0	10.7	0.84	6.7	8.8	0.0004	8.5	5.1
CGCM3 RCP 8.5	0.78	7.9	10.7	0.84	6.6	8.8	0.0002	8.3	4.7
BCC RCP 4.5	0.66	7.7	10.5	0.70	6.8	8.9	0.0000	9.2	6.3
BCC RCP 8.5	0.74	6.8	9.8	0.70	6.8	8.9	0.0000	9.3	6.4
CCSM4 RCP 4.5	0.72	4.6	8.5	0.86	3.2	8.2	0.0006	11.3	9.4
CCSM4 RCP 8.5	0.72	4.6	8.5	0.86	3.2	8.1	0.0008	11.4	9.5
HadGEM RCP 4.5	0.81	8.8	10.0	0.84	6.9	9.2	0.0074	8.5	6.0
HadGEM RCP 8.5	0.81	8.9	10.0	0.83	6.9	9.2	0.0061	8.6	6.0
MIROC5 RCP 4.5	0.78	13.9	11.3	0.78	12.2	9.0	0.0043	8.2	5.1
MIROC5 RCP 8.5	0.78	14.0	11.3	0.78	12.5	9.1	0.0045	8.2	5.2
CSIRO RCP 4.5	0.81	9.4	9.3	0.82	7.1	9.3	0.0019	8.9	6.4
CSIRO RCP 8.5	0.81	9.3	9.3	0.82	7.1	9.3	0.0017	8.8	6.2
GFDL RCP 4.5	0.81	12.0	9.2	0.72	11.6	9.1	0.0009	8.4	5.3
GFDL RCP 8.5	0.80	12.1	9.1	0.72	11.7	9.0	0.0008	8.6	5.7

Table S2. R^2, RMSE, and SD calculated from observed and GCMs biasally corrected data for Tmax, Tmin and precipitation for the period of 1981–2010.

	Rank	**Maximum Temperature**			**Minimum Temperature**			**Precipitation**		
		R^2	**RMSE (°C)**	**SD (°C)**	**R^2**	**RMSE (°C)**	**SD (°C)**	**R^2**	**RMSE (mm)**	**SD (mm)**
Observed	0	1.00	0.0	7.9	1.00	0.0	6.8	1.00	0.0	6.5
CGCM3 RCP 4.5	7	0.76	4.0	8.1	0.80	3.2	7.2	0.0014	12.2	10.6
CGCM3 RCP 8.5	7	0.77	4.0	8.1	0.80	3.2	7.2	0.0015	12.5	10.9
BCC RCP 4.5	6	0.60	5.8	9.1	0.65	4.7	8.0	0.0020	12.0	10.4
BCC RCP 8.5	6	0.72	4.5	8.3	0.65	4.7	8.0	0.0032	12.2	10.6
CCSM4 RCP 4.5	5	0.73	4.3	8.3	0.84	2.9	7.1	0.0039	11.9	10.3
CCSM4 RCP 8.5	5	0.74	4.3	8.3	0.84	2.9	7.1	0.0042	11.9	10.4
HadGEM RCP 4.5	1	0.78	3.8	8.0	0.79	3.4	7.3	0.0120	8.4	6.0
HadGEM RCP 8.5	1	0.78	3.9	8.0	0.78	3.4	7.3	0.0095	8.4	6.0
MIROC5 RCP 4.5	3	0.77	4.0	8.0	0.77	3.5	7.3	0.0053	9.6	7.6
MIROC5 RCP 8.5	3	0.77	4.0	8.0	0.76	3.6	7.4	0.0051	9.6	7.5
CSIRO RCP 4.5	2	0.80	3.7	7.9	0.77	3.6	7.4	0.0066	8.5	6.0
CSIRO RCP 8.5	2	0.80	3.6	7.9	0.77	3.6	7.4	0.0060	8.6	6.1
GFDL RCP 4.5	4	0.79	3.8	8.0	0.66	4.7	8.0	0.0054	10.1	8.2
GFDL RCP 8.5	4	0.79	3.8	8.0	0.66	4.7	8.0	0.0048	10.3	8.4

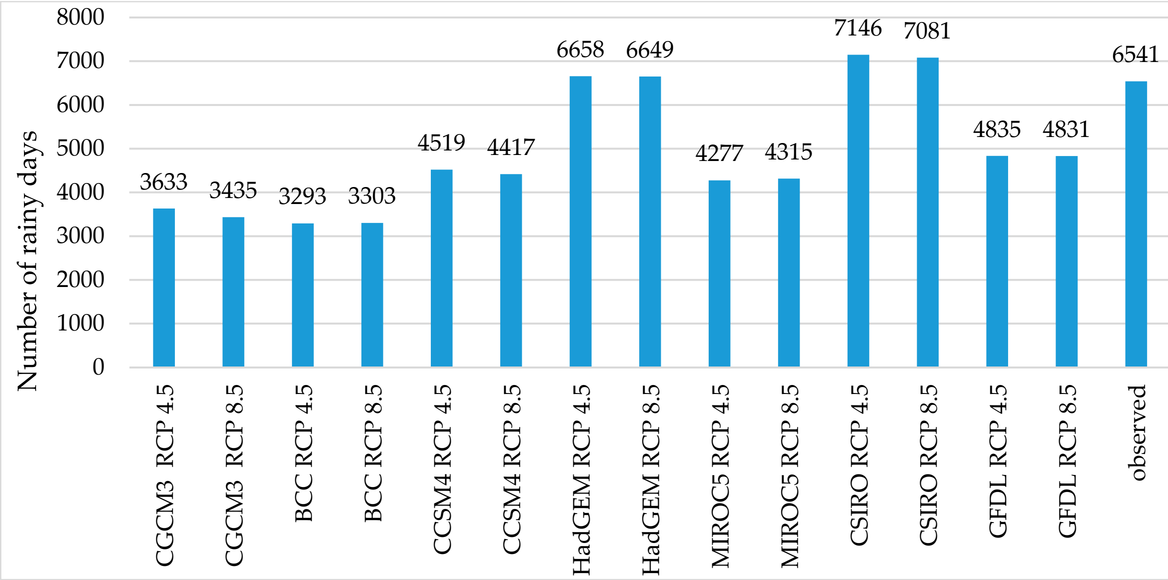


Figure S2. Number of rainy days the Jhelum River basin (Raw data for the period of 1981–2010).

Supplementary Material B: Calibration and Validation of SWAT Model for Mangla Basin

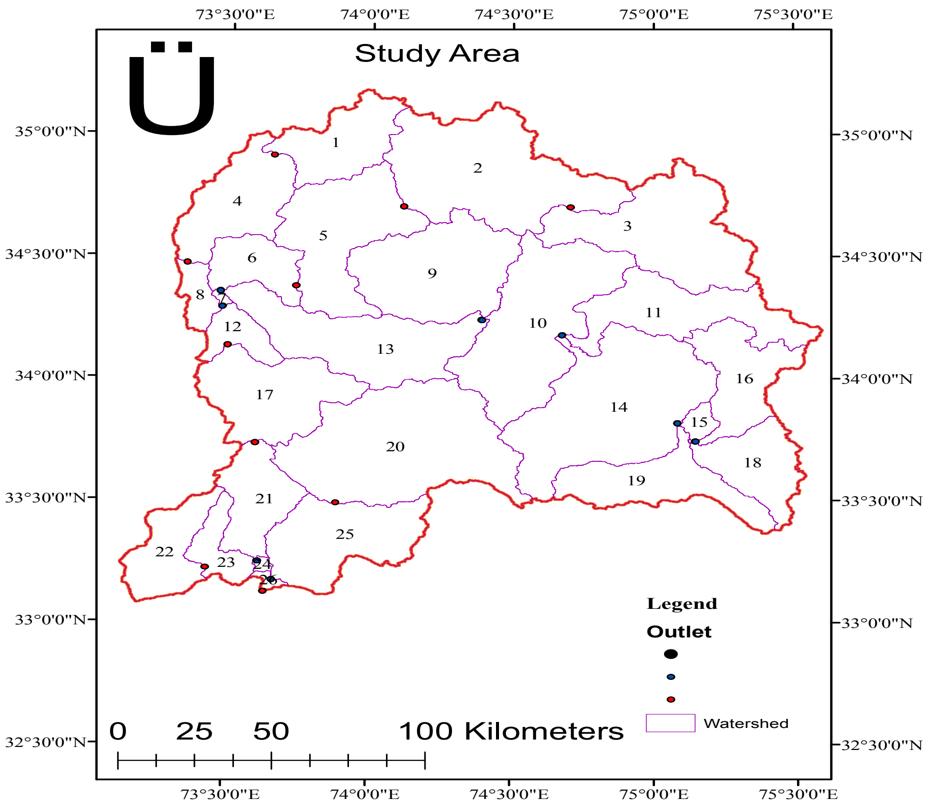


Figure S3. Study Area showing various sub-basins.

There are 375 HRU were created for 26 sub-basins for study area.

Slope of the Watershed

Table S3. Slope characteristics of the sub-basins.

Slope	Mangla	Kahan	Kanshi	Poonch	Kunhar	Neelum	Upper Jhelum
Min	0	0	0	0	0	0	0
Mean	39.2	11.4	4.77	35.2	53.8	56.5	33.7
Max	458	92	56.7	252	437	458	252
Std dev	27.8	12.8	4.19	22	25.2	25.2	27.5
Slope (%)	Mangla	Kahan	Kanshi	Poonch	Kunhar	Neelum	Upper Jhelum
	%	%	%	%	%	%	%
max	1.18	0.00	0.00	0.11	4.27	4.89	0.47
90	20.32	0.00	0.00	11.18	34.19	37.12	17.14
60	37.87	10.99	0.00	44.31	46.38	47.74	31.63
30	19.90	25.85	6.59	31.63	13.91	10.08	19.76
10	20.73	63.16	93.41	12.77	1.25	0.17	31.00

Land Use Data

MODIS supplies global maps of land cover at 500 × 500 m spatial resolution. There are 17 land cover types in the Jhelum Basin, as shown in Table S4.

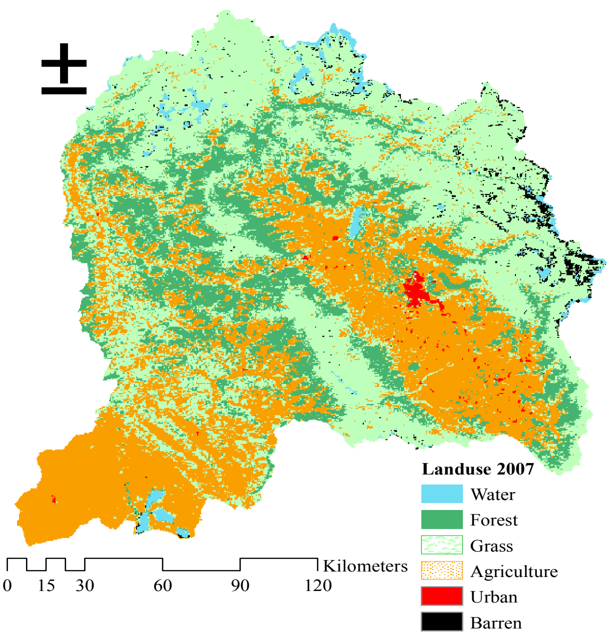


Figure S4. Land use map of the Mangla Basin.

Table S4. Land use types (in percentage) in each sub-basin in 2007.

No.	Land Use Types	Mangla	Upper Jhelum	Neelum	Kunhar	Poonch	Kanshi	Kahan
1	Water bodies	0.6	0.2	0.7	0.8	0.6		9.8
2	Forest Evergreen Needle leaf	5.3	7.4	6.7	4.3	2.1		
3	Forest Evergreen Broad leaf	0.0	0.0	0.0	0.0	0.0		
4	Forest Decidious Needle leaf	0.1	0.0	0.2	0.0	0.0		
5	Forest Decidious Broad leaf	0.1	0.1	0.1	0.0	0.0		0.2
6	Mixed Forest	14.4	14.5	13.8	12.2	19.1	0.0	0.6
7	Close Shrub land	1.2	0.8	0.6	1.3	1.9	0.2	2.3
8	Open Shrub land	4.1	4.1	7.0	6.8	0.6	0.9	4.3
9	Woody Savannas	5.2	3.4	3.7	5.7	9.5	0.1	2.7
10	Savannas	0.6	0.7	0.8	0.4	0.3		0.1
11	Grasslands	27.8	29.1	42.4	48.0	11.7	1.6	4.0
12	Permanent Wetland	0.2	0.2	0.1	0.1	0.5		0.4
13	Croplands	30.5	31.0	9.8	12.7	40.3	94.4	72.0
14	Urban and Builltup	0.5	1.1	0.0		0.1	0.3	
15	Cropland/Natural Vegetation Mosaic	5.7	4.5	5.7	1.9	12.7	2.4	3.3
16	Snow and Ice	1.2	0.6	3.5	1.9	0.1		
17	Barren and Sparse vegetation	2.5	2.3	5.2	3.9	0.6	0.0	0.2

Source: MODIS Land Use Data

Table S5. Hypsometric analysis of the Mangla Basin.

No.	Elevation (M)	Mangla	Upper Jhelum	Neelum	Kunhar	Poonch	Kanshi	Kahan
1	500	4.74	0.00	0.00	0.00	5.19	56.88	69.60
2	1000	8.61	0.40	0.58	2.75	25.94	43.12	28.86
3	1500	7.74	1.63	2.66	7.77	27.47		1.54
4	2000	22.23	37.82	5.14	8.54	16.83		
5	2500	12.75	18.14	10.25	9.67	9.96		
6	3000	12.30	14.28	18.70	11.73	6.79		
7	3500	11.14	10.87	21.84	14.02	3.60		
8	4000	11.36	10.56	21.48	20.83	2.93		
9	4500	8.08	5.61	16.72	22.56	1.28		
10	5000	1.00	0.68	2.42	2.14	0.02		
11	5500	0.05	0.02	0.20	0.003			
12	6000	0.002		0.003				
13	6276	0.004		0.002				

Source: SRTM DEM Data

Table S6. Elevation bands maximum and minimum of each basin (26 sub-basins).

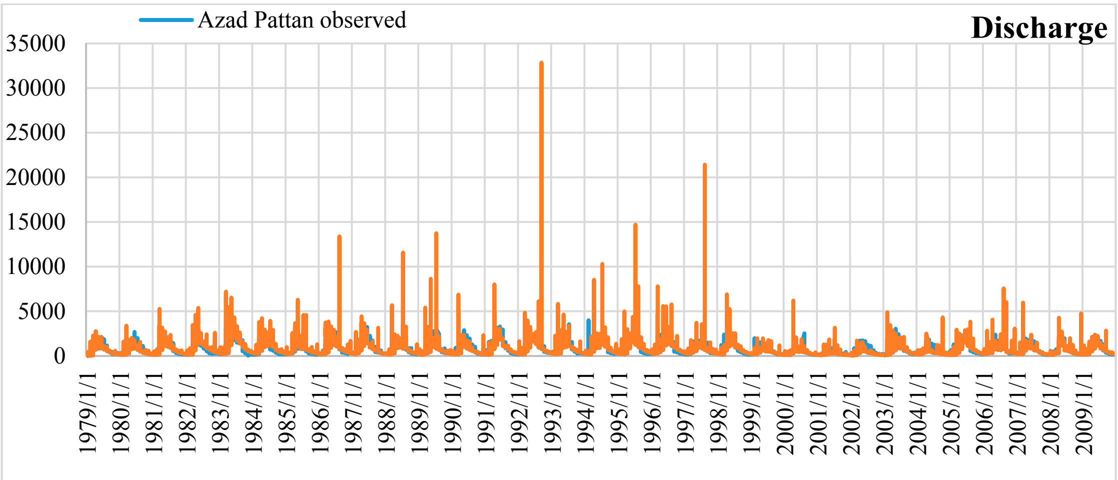
No.	Min	Max	No.	Min	Max
1	2435	5077	14	1554	4664
2	1792	6285	15	1590	2897
3	2279	5170	16	1595	5232
4	877	5160	17	446	3383
5	742	4977	18	1594	4406
6	666	4419	19	1589	4680
7	633	1437	20	512	4698
8	642	2710	21	316	1697
9	1569	4309	22	385	867
10	1562	5062	23	320	837
11	1570	5335	24	300	563
12	579	2906	25	323	2092
13	669	4302	26	255	630

Table S7. Fraction of area in each elevation band (26 sub-basins).

(a)														
No.	Elevation (M)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0													
2	1000				0.01		0.06	0.71	0.21				0.15	0.03
3	1500				0.06	0.03	0.21	0.29	0.43				0.40	0.12
4	2000		0.01		0.12	0.11	0.24		0.24	0.48	0.50	0.13	0.33	0.28
5	2500	0.00	0.08	0.01	0.17	0.19	0.23		0.10	0.24	0.12	0.10	0.10	0.26
6	3000	0.05	0.20	0.12	0.20	0.25	0.17		0.02	0.16	0.11	0.13	0.02	0.20
7	3500	0.13	0.24	0.27	0.18	0.18	0.07			0.08	0.12	0.16		0.08
8	4000	0.34	0.23	0.33	0.15	0.12	0.02			0.03	0.11	0.23		0.03
9	4500	0.44	0.19	0.25	0.10	0.10				0.01	0.04	0.20		
10	6300	0.04	0.05	0.02	0.01	0.02						0.05		

(b)														
No.	Elevation (M)	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0													
2	1000				0.18			0.15	0.94	1	1	1	0.81	1
3	1500				0.34			0.30	0.06				0.16	
4	2000	0.52	0.84	0.13	0.34	0.27	0.31	0.21					0.03	
5	2500	0.18	0.14	0.12	0.10	0.24	0.21	0.14						
6	3000	0.10	0.02	0.13	0.03	0.19	0.19	0.09						
7	3500	0.08		0.16	0.01	0.15	0.13	0.05						
8	4000	0.08		0.25		0.12	0.11	0.04						
9	4500	0.04		0.17		0.03	0.04	0.02						
10	6300			0.04			0.01							

Daily Discharge Calibration



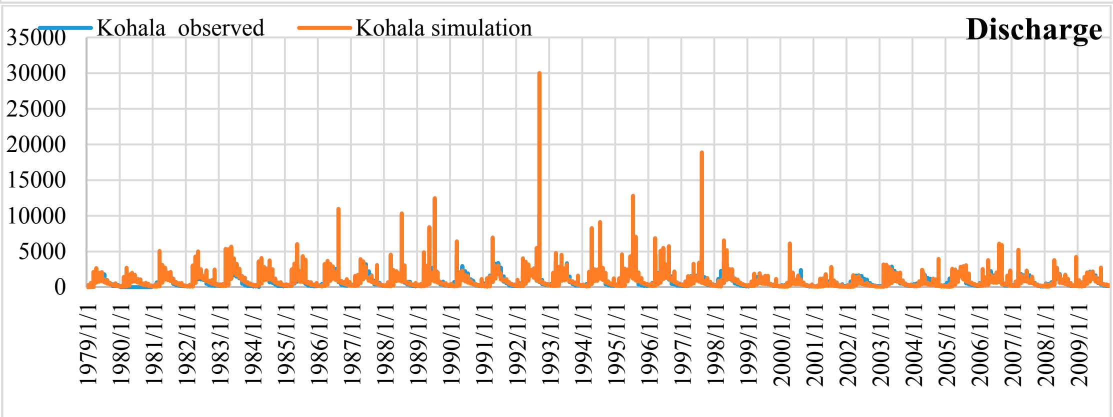


Figure S5. *Cont.*

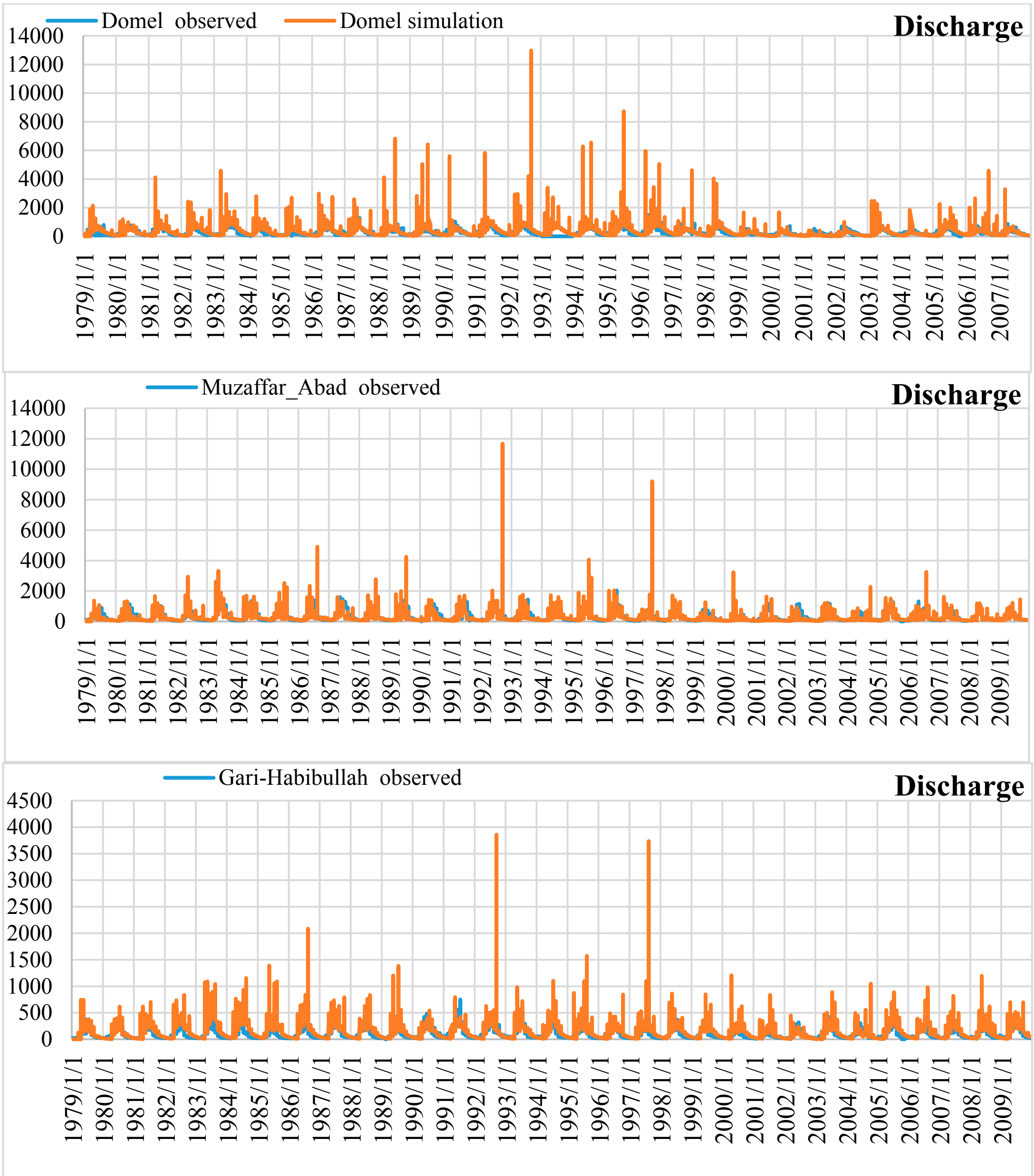
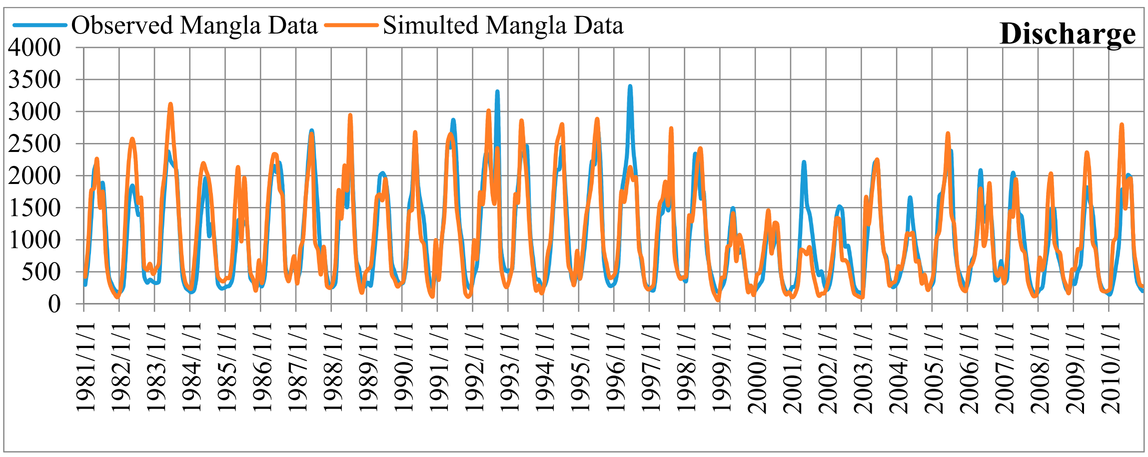


Figure S5. Daily observed and simulated discharge.

Monthly Discharge Calibration



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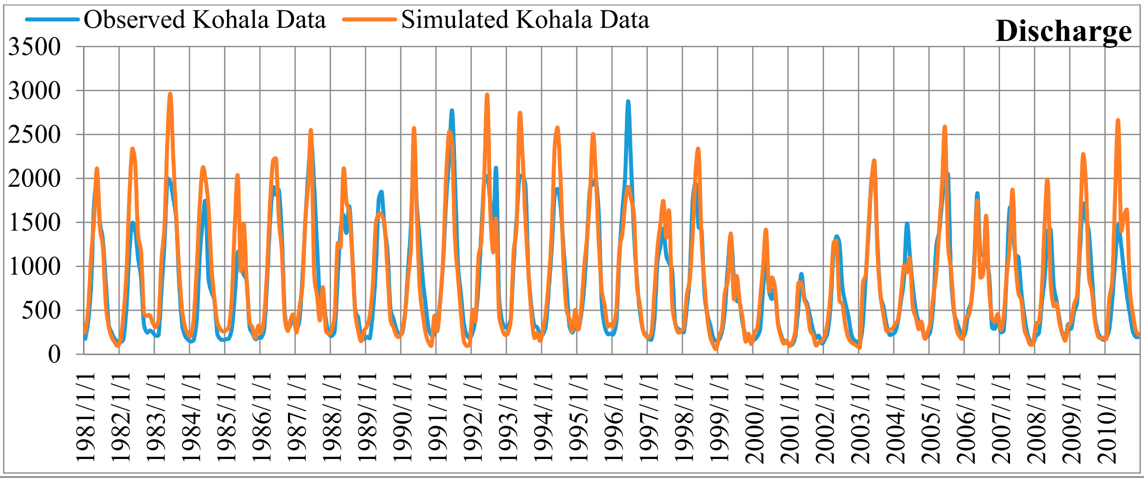
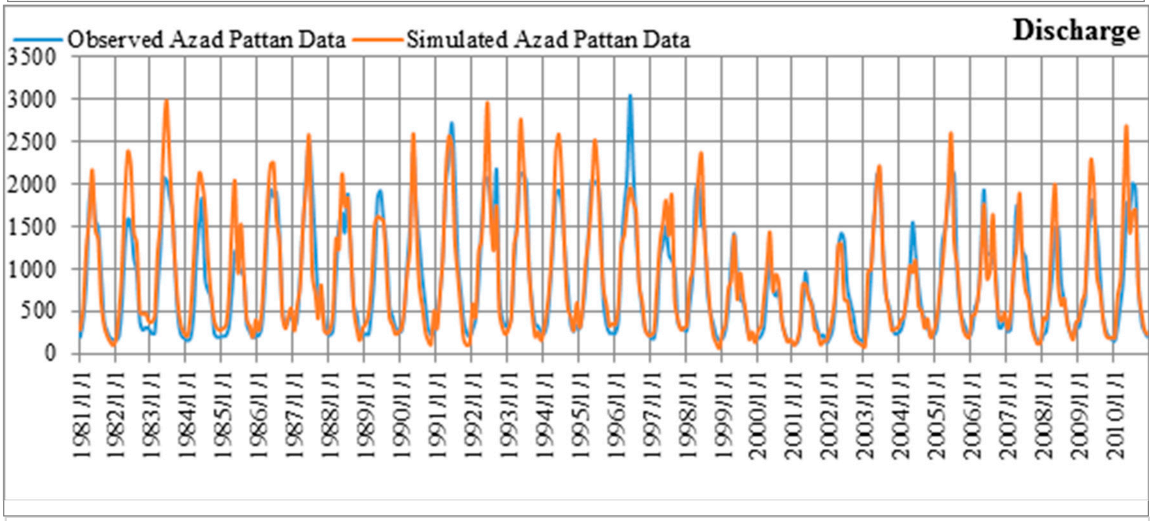

Observed Kohala Data
Simulated Kohala Data
Discharge
3500
3000
2500
2000
1500
1000
500
0
1981/1/1 1982/1/1 1983/1/1 1984/1/1 1985/1/1 1986/1/1 1987/1/1 1988/1/1 1989/1/1 1990/1/1 1991/1/1 1992/1/1 1993/1/1 1994/1/1 1995/1/1 1996/1/1 1997/1/1 1998/1/1 1999/1/1 2000/1/1 2001/1/1 2002/1/1 2003/1/1 2004/1/1 2005/1/1 2006/1/1 2007/1/1 2008/1/1 2009/1/1 2010/1/1


Observed Azad Pattan Data
Simulated Azad Pattan Data
Discharge
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500
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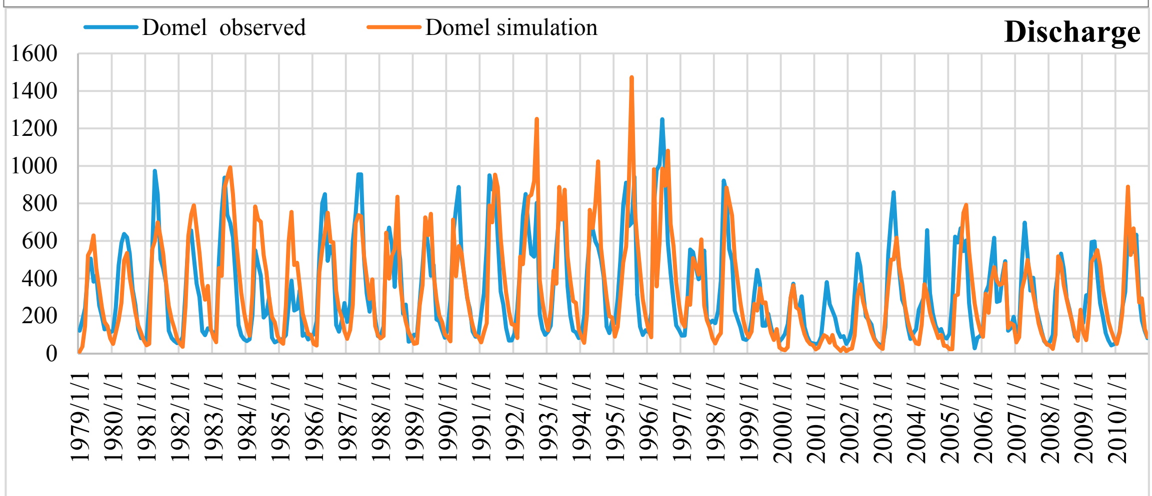
Domel observed
Domel simulation
Discharge
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1200
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1979/1/1 1980/1/1 1981/1/1 1982/1/1 1983/1/1 1984/1/1 1985/1/1 1986/1/1 1987/1/1 1988/1/1 1989/1/1 1990/1/1 1991/1/1 1992/1/1 1993/1/1 1994/1/1 1995/1/1 1996/1/1 1997/1/1 1998/1/1 1999/1/1 2000/1/1 2001/1/1 2002/1/1 2003/1/1 2004/1/1 2005/1/1 2006/1/1 2007/1/1 2008/1/1 2009/1/1 2010/1/1

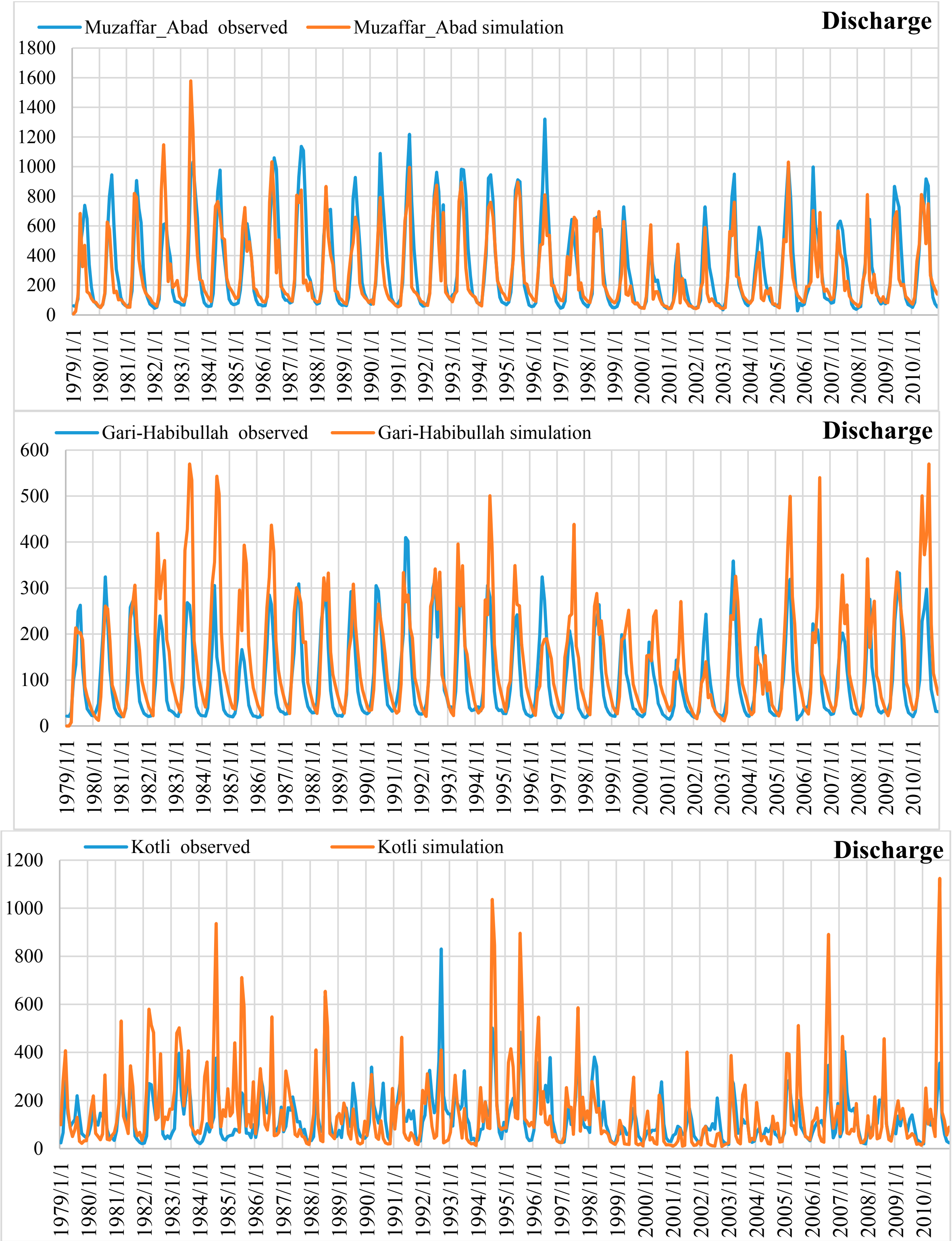

Figure S6. *Cont.*

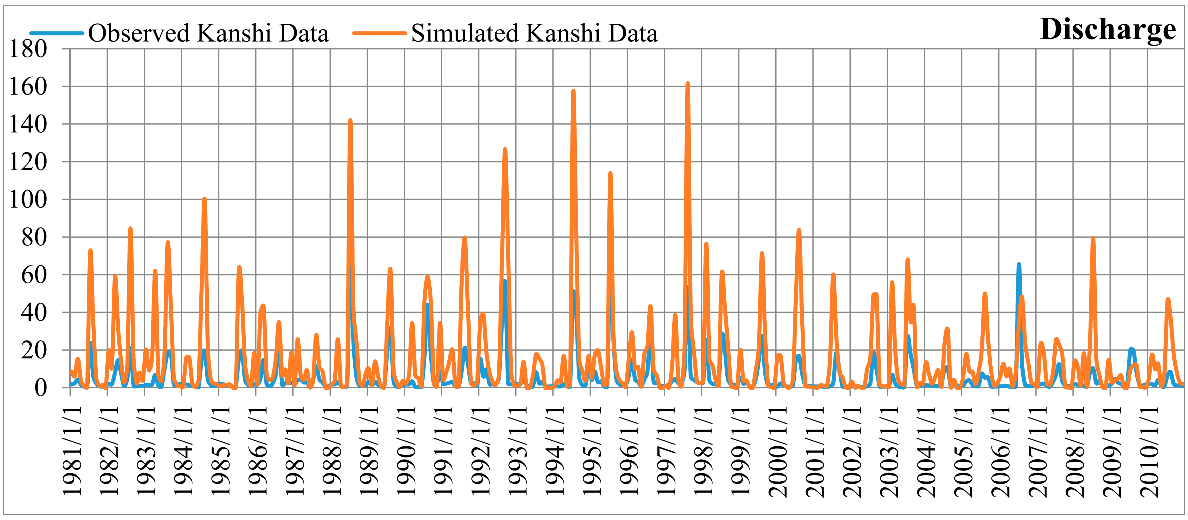

Figure S6. Monthly observed and simulated discharge.

References

1. Hulme, M. (Ed.) *Climate Change and Southern Africa: An Exploration of Some Potential Impacts and Implications for the SADC Region*; Climatic Research Unit, University of East Anglia: Norwich, UK, 1996; pp. 1–104.
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3. Feenstra, J.F.; Burton, I.; Smith, J.B.; Tol, R.S. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*; United Nations Environment Programme: Nairobi, Kenya, 1998; Volume 2.