

Supplemental Information

The Kerala flood of 2018: the combined impact of extreme rainfall and reservoir storage

Vimal Mishra^{1*}, Saran Aadhar¹, Harsh Shah¹, Rahul Kumar¹, D. R. Pattanaik², Amar Deep Tiwari¹

¹Civil Engineering, Indian Institute of Technology Gandhinagar, Gandhinagar, 382355, India

²India Meteorological Department, New Delhi, 110003, India

Correspondence to: Vimal Mishra (vmishra@iitgn.ac.in)

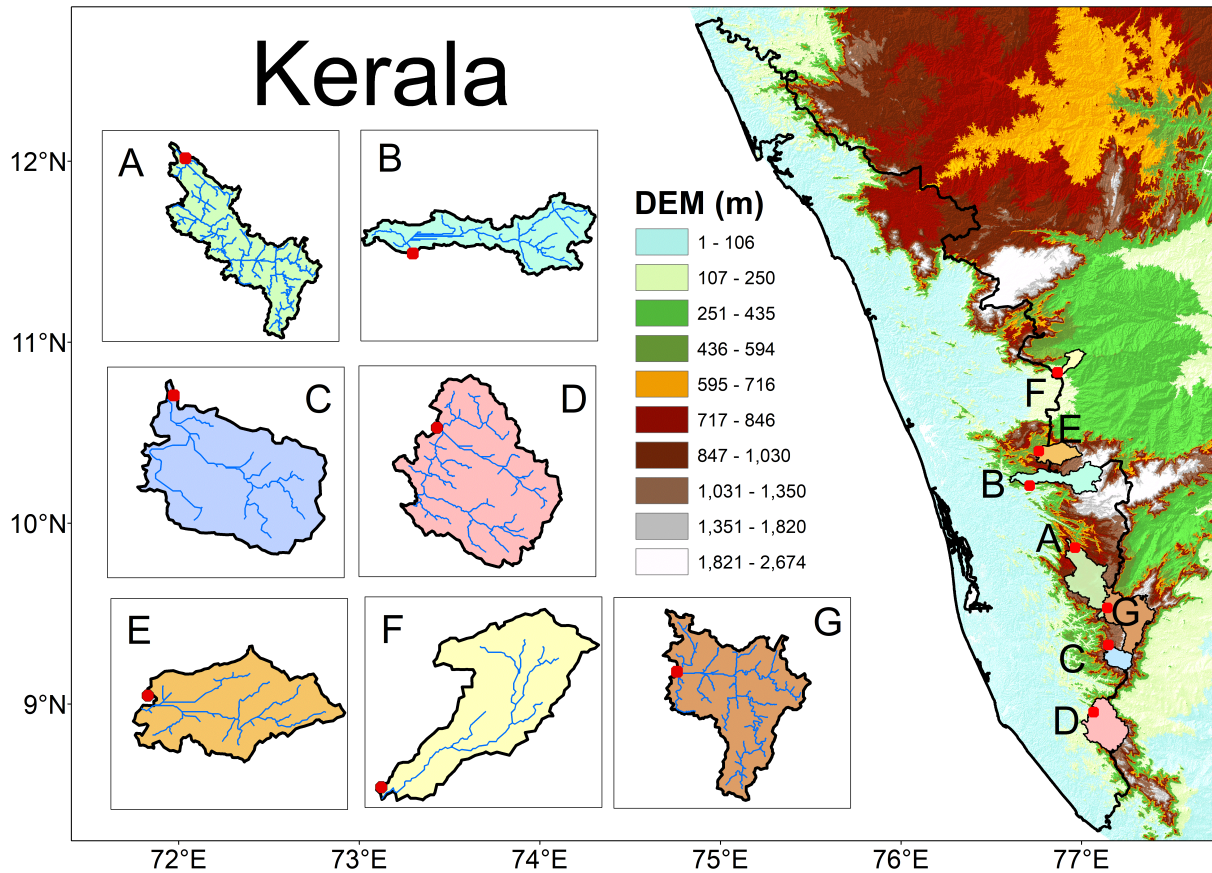


Figure S1: Location of major reservoirs in Kerala and their catchments in the upstream regions.

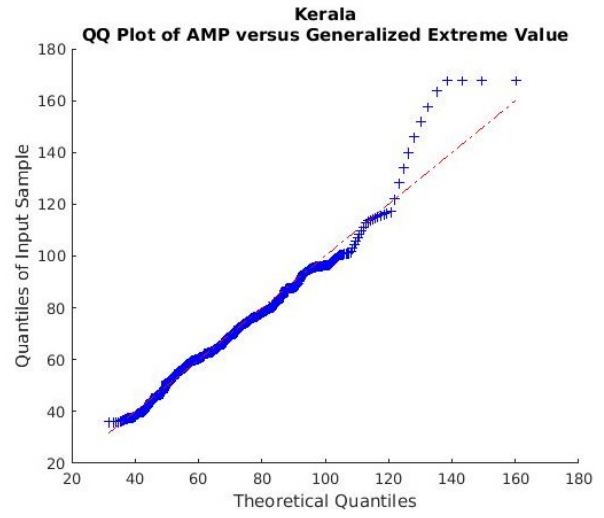
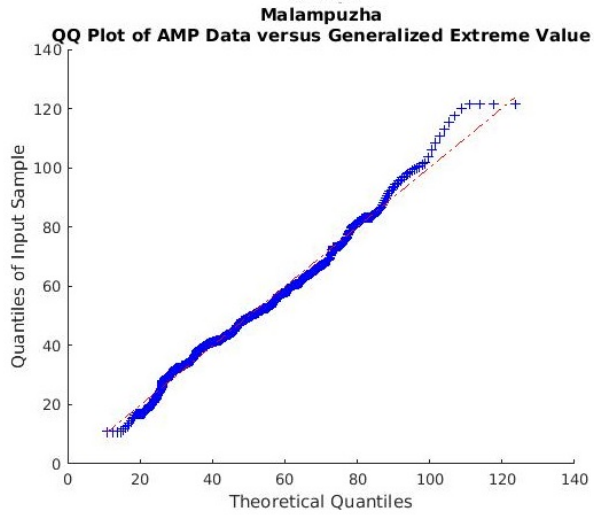


Figure S2: Q-Q plot for (a) Malampuzha reservoir and (b) Kerala state.

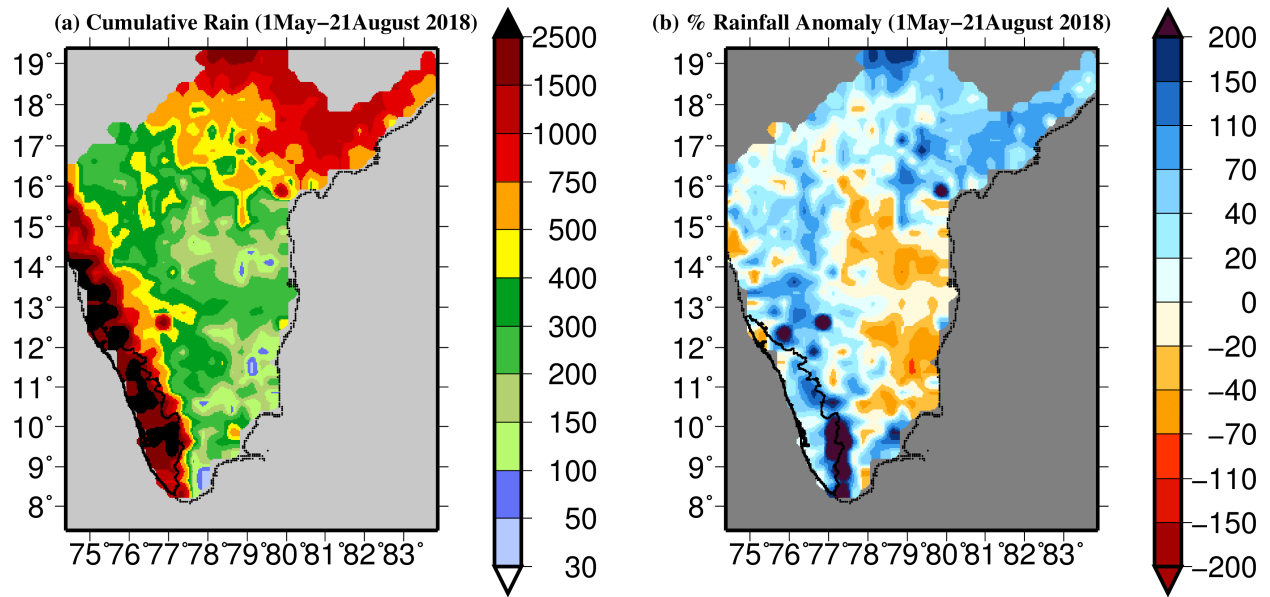


Figure S3: (a) Cumulative rainfall for 1 May - 21 August 2018 and (b) rainfall anomaly (%) for 1 May - 21 August 2018 estimated using average rainfall for 1901-2017 period.

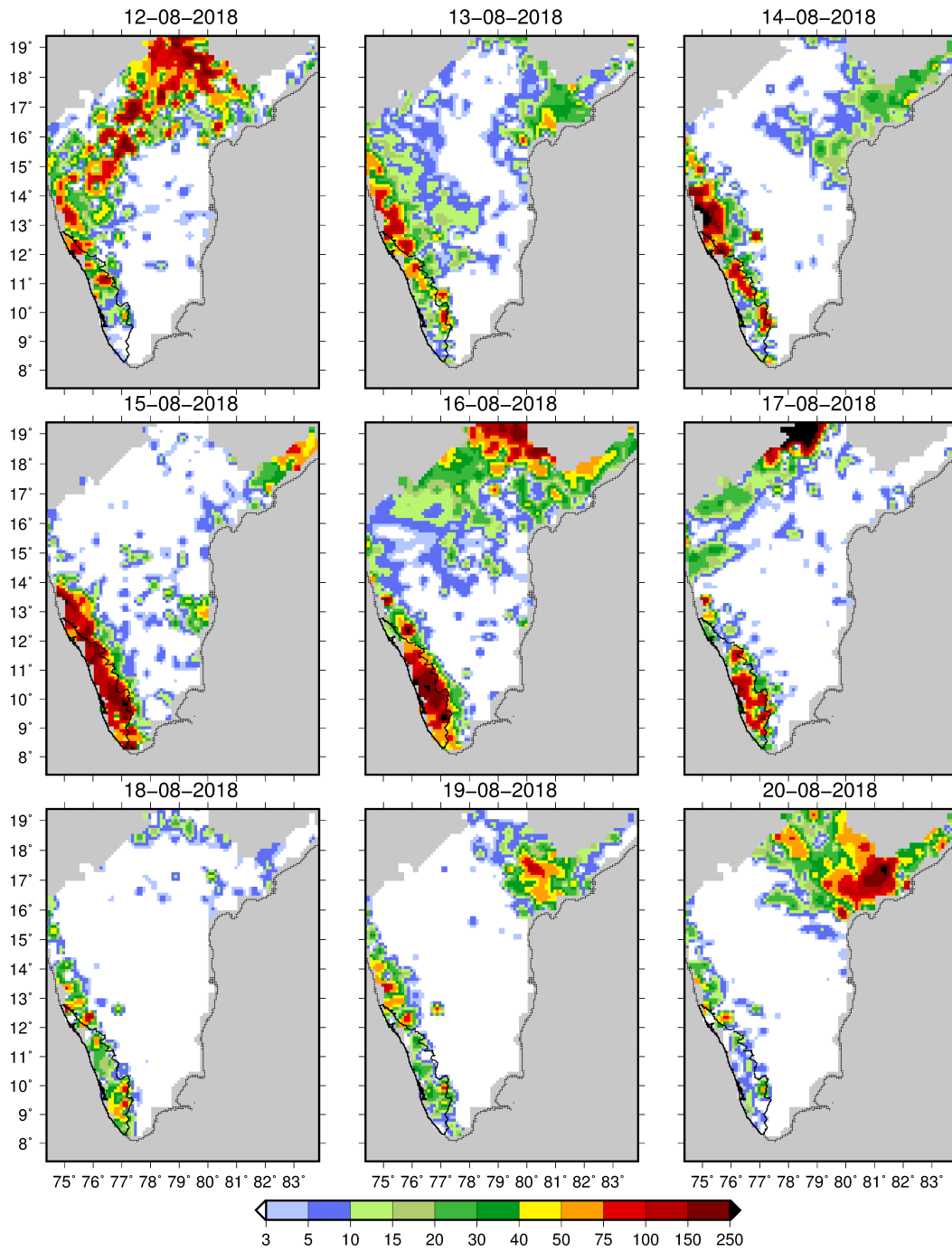


Figure S4: Daily rainfall (mm) in Kerala from India Meteorological Department (IMD) from 12 to 20 August 2018.

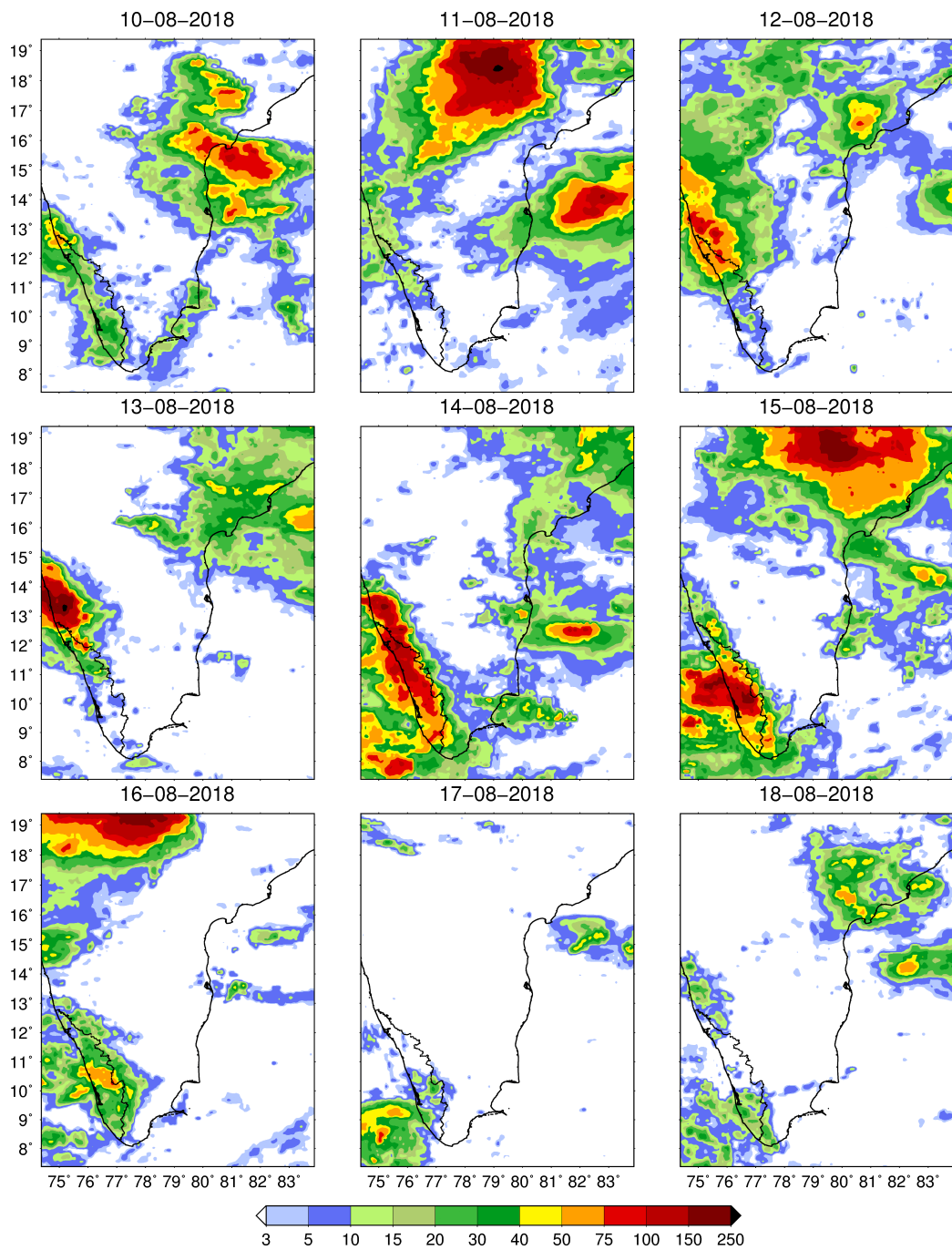


Figure S5: Daily rainfall (mm) in Kerala from NASA's Global Precipitation Mission (GPM) from 10 to 18 August 2018.

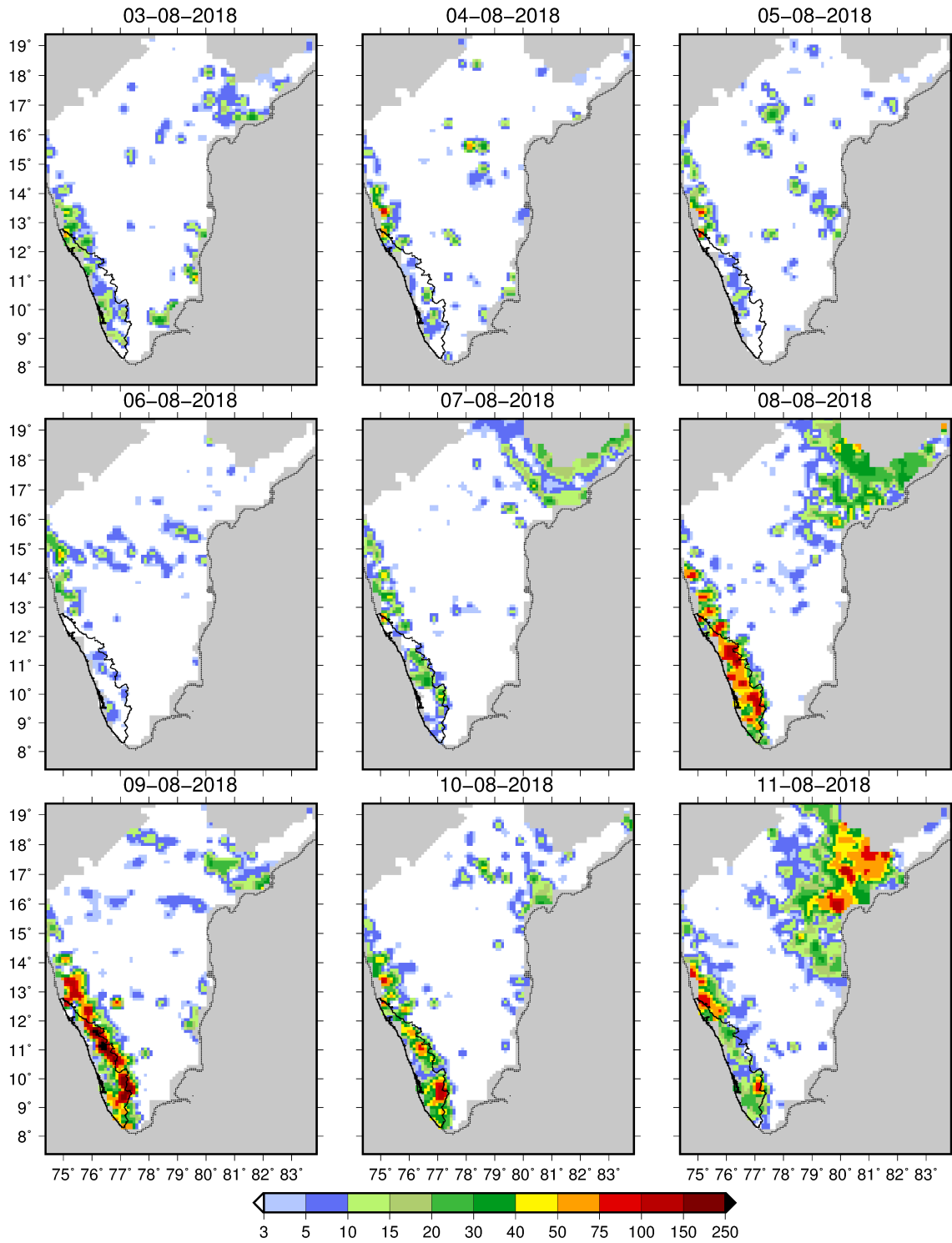


Figure S6: Daily rainfall (mm) in Kerala from India Meteorological Department (IMD) from 3 to 11 August 2018.

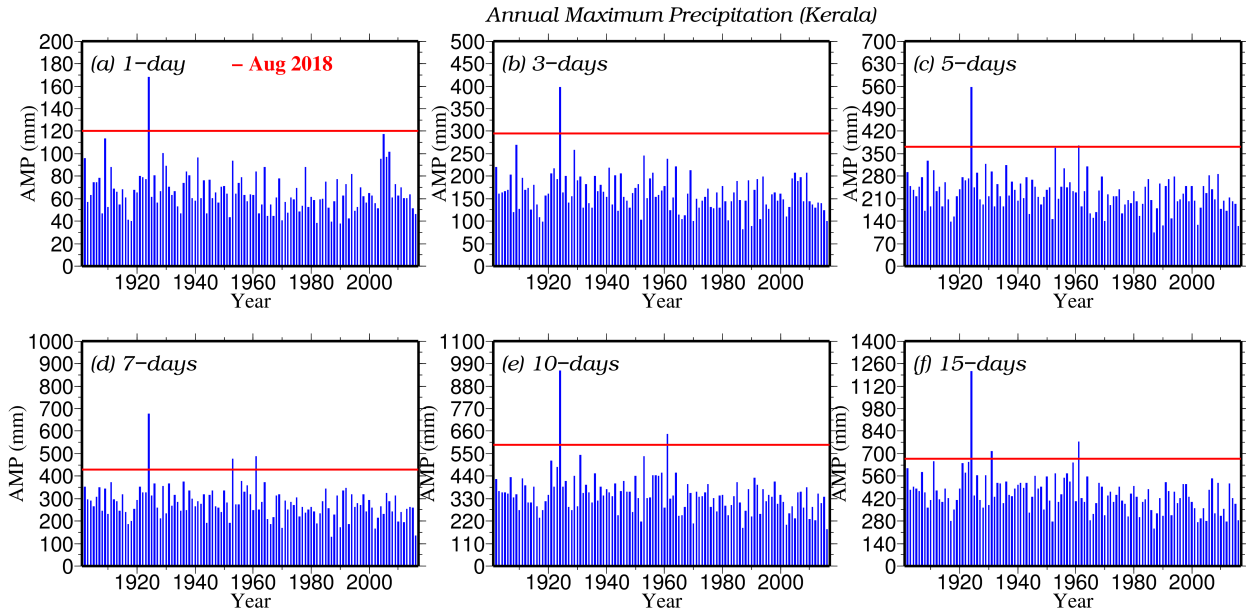


Figure S7: Annual Maximum rainfall (mm) for cumulative 1-day, 3-days, 5-days, 10-days and 15-days for the period 1901-2017 in Kerala and red lines show the cumulative rainfall (for 1, 3, 5, 7, 10 and 15-days) during August 2018.

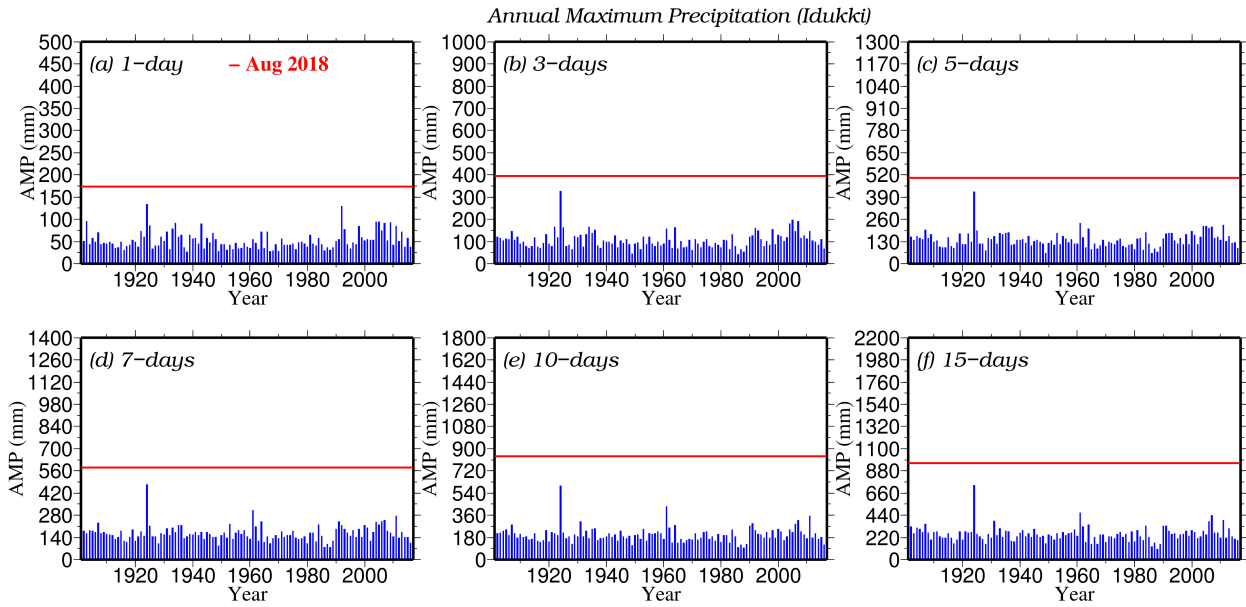


Figure S8: Same as figure S7 but for Idukki reservoir catchment.

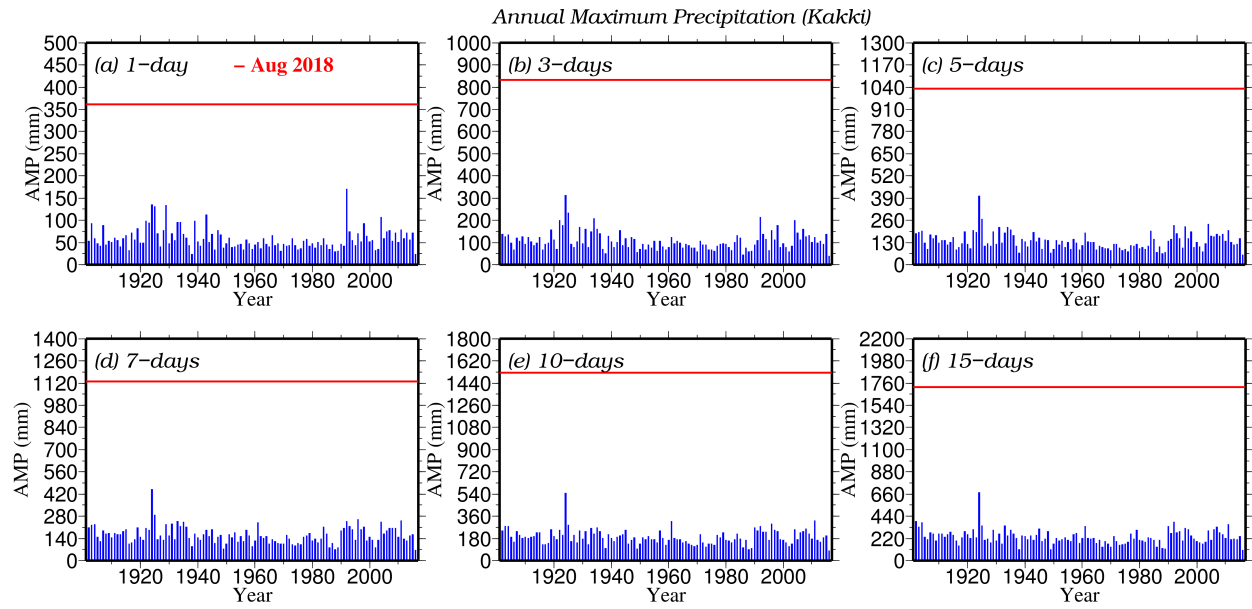


Figure S9: Same as figure S7 but for Kakki reservoir catchment.

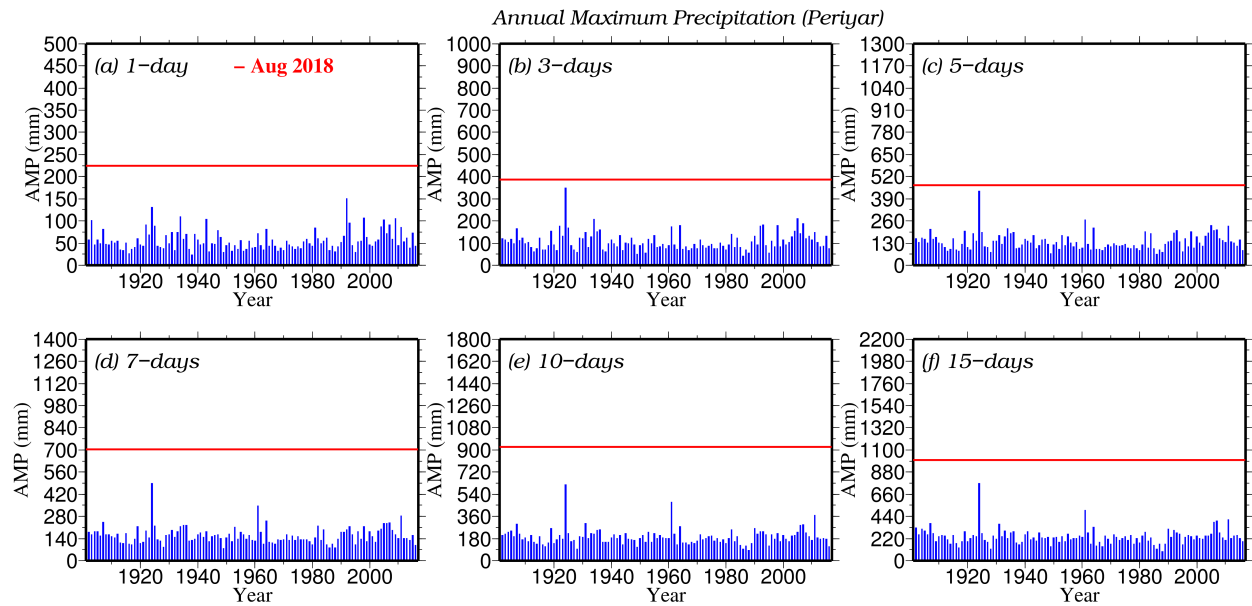


Figure S10: Same as figure S7 but for Periyar reservoir catchment.

Table S1: Goodness of fit statistics estimated using the Chi-square test on annual maximum precipitation for seven reservoirs for 1-15 days duration. P-value higher than 0.05 indicates that the null hypothesis (the data follow the GEV distribution) cannot be rejected.

Duration	P-value							
	Idukki	Parambikulam	Idamalayar	Malampuzha	Kakki	Kallada	Periyar	Kerala state
1	0.183	0.072	0.347	0.213	0.028	0.068	0.440	0.459
2	0.439	0.039	0.003	0.064	0.061	0.150	0.232	0.270
3	0.261	0.067	0.001	0.207	0.402	0.433	0.151	0.091
4	0.127	0.308	0.301	0.291	0.175	0.844	0.242	0.113
5	0.450	0.227	0.254	0.083	0.059	0.301	0.145	0.037
6	0.060	0.145	0.221	0.170	0.028	0.301	0.314	0.003
7	0.291	0.205	0.131	0.061	0.083	0.210	0.109	0.010
8	0.147	0.115	0.403	0.179	0.028	0.221	0.114	0.028
9	0.026	0.192	0.235	0.114	0.311	0.208	0.011	0.001
10	0.009	0.597	0.113	0.028	0.131	0.063	0.020	0.002
11	0.000	0.325	0.146	0.023	0.154	0.203	0.017	0.003
12	0.001	0.599	0.300	0.036	0.039	0.056	0.052	0.001
13	0.003	0.187	0.535	0.320	0.042	0.096	0.050	0.006
14	0.007	0.260	0.114	0.233	0.016	0.092	0.006	0.002
15	0.025	0.447	0.070	0.371	0.005	0.083	0.011	0.004

Table S2: Rainfall depth for 5-500 year return period for duration 1-15 days over Kerala.

Duration	Rainfall Depth (Return Period)						
	5	10	20	50	100	200	500
1	79.08	89.87	100.36	114.17	124.67	135.29	149.51
2	142.67	161.23	178.84	201.35	218.03	234.47	255.91
3	194.21	218.90	242.07	271.33	292.74	313.63	340.54
4	236.64	266.12	293.47	327.59	352.24	376.04	406.32
5	273.80	307.54	338.58	376.91	404.34	430.60	463.69
6	307.78	345.42	379.91	422.32	452.51	481.32	517.46
7	337.89	378.96	416.52	462.59	495.33	526.49	565.51
8	367.05	413.37	456.40	510.10	548.93	586.44	634.22
9	394.74	445.62	493.30	553.42	597.32	640.10	695.12
10	421.07	476.01	527.73	593.28	641.38	688.46	749.30
11	447.32	506.37	562.06	632.78	684.78	735.76	801.77
12	473.01	535.17	593.43	666.93	720.63	772.97	840.31
13	497.97	562.98	623.78	700.26	755.98	810.18	879.72
14	521.47	589.69	653.54	733.95	792.58	849.66	922.96

15	544.48	615.74	682.32	766.00	826.90	886.08	961.95
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Table S3: Return period for August 2018 rainfall for 1-15 days duration over Kerala.

Duration	Return Period (years)
1	75
2	209
3	105
4	69
5	44
6	31
7	26
8	27
9	37
10	49
11	43
12	35
13	27
14	21
15	17

Table S4: Maximum rainfall over Kerala during 1-21 August 2018.

Duration	Rainfall (Aug 2018)
1	120.28
2	235.50
3	294.24
4	339.35
5	371.74
6	400.67
7	429.45
8	473.99
9	533.11
10	591.84
11	620.77
12	637.95
13	648.79
14	658.48
15	666.62

Table S5: Percentage of Full Reservoir Level (FRL) filled for all 7 reservoirs during the flood.

Reservoir	% of FRL
Idukki	92.5
Idamalayar	97.3
Kakki	97.3
Kallada	90.5
Malampuzha	97.8
Parambikulam	99.5
Periyar	79.8

Table S6: Rainfall depth for all 7 reservoirs and Kerala during the flood (1 August-21 August).

Reservoir	(1 May-21 August) Cumulative Rainfall (mm)					Departure (%) from Mean	1 May-7 Aug 2018
	Mean	Std	1924	1961	2018		
Idukki	758.6	208.3	1405.54	1220.7	2880.2	279.7	1936.2
Parambikulam	1155.2	403.8	1797.01	2055.4	1590.6	37.7	1132.2
Idamalayar	1431.7	365.5	2451.22	2112.7	2235.2	56.1	1564.0
Malampuzha	422.4	190.3	793.65	768.3	743.4	76.0	510.0
Kakki	531.2	227.8	1201.97	830.4	4252.9	700.6	2556.0
Kallada	562.3	248.2	1107.66	1486.2	1663.9	195.9	1037.5
Periyar	634.9	222.7	1321.96	1087.0	3314.8	422.1	2323.7
Kerala	1490	333	2670	2536	2290	53.7	1634.5401

Table S7: Rainfall depth over seven reservoirs for 500 year return period.

Rainfall Depth (500 Year)							
Duration	Idukki	Parambikulam	Idamalayar	Malampuzha	Kakki	Kallada	Periyar
1	193.53	214.47	199.46	117.55	175.13	245.93	201.24
2	241.52	335.90	330.75	172.05	256.73	326.94	276.49
3	276.82	458.01	438.77	211.38	292.78	388.46	331.22
4	307.60	559.96	524.03	254.53	322.80	409.49	361.36
5	334.74	632.68	609.46	287.77	346.33	442.50	392.31
6	360.50	688.08	690.50	309.16	365.47	466.48	406.71
7	376.92	731.14	745.53	338.17	381.57	480.02	410.94
8	406.41	781.07	784.52	364.05	397.55	508.14	432.79
9	447.41	858.67	859.97	386.13	428.64	515.08	473.06
10	471.75	935.04	907.32	418.62	446.33	516.16	491.19
11	496.99	976.03	942.71	432.97	475.25	529.01	518.28
12	510.63	1011.22	956.54	451.84	491.98	564.70	528.80

13	527.97	1053.27	987.92	476.13	510.40	585.22	544.89
14	548.14	1098.27	1018.57	488.28	531.29	608.80	561.40
15	565.71	1136.66	1073.23	501.71	545.08	624.12	573.87

Table S8: Maximum rainfall over seven reservoirs during 1-21 August 2018.

Rainfall Depth (2018)							
Duration	Idukki	Parambikulam	Idamalayar	Malampuzha	Kakki	Kallada	Periyar
1	172.93	135.26	165.06	70.95	361.66	122.71	224.78
2	316.97	269.59	310.55	100.60	622.66	191.50	322.16
3	394.52	294.13	387.29	108.40	832.31	302.89	386.42
4	452.44	317.79	431.95	111.45	941.05	355.49	454.55
5	501.38	323.14	458.78	128.85	1030.64	361.81	468.50
6	547.08	332.18	479.77	136.65	1082.03	380.62	604.23
7	579.81	340.23	499.34	148.55	1129.14	386.95	701.61
8	684.12	385.47	514.92	217.13	1202.71	412.07	820.06
9	761.68	425.52	556.02	225.04	1412.36	483.21	917.44
10	836.98	449.18	605.79	232.84	1525.86	556.69	924.93
11	882.68	459.54	632.62	233.86	1634.60	609.28	934.76
12	915.42	463.86	652.20	233.86	1681.70	622.24	948.77
13	931.02	465.75	662.85	234.27	1703.34	628.57	968.10
14	944.03	466.74	672.49	234.41	1703.63	636.50	991.14
15	956.90	468.82	681.78	234.65	1718.49	639.97	998.62