Role of hydrometeorological variables and catchment area to flood generation over the monsoonal climate region of India

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Supplemental Figures and Tables:

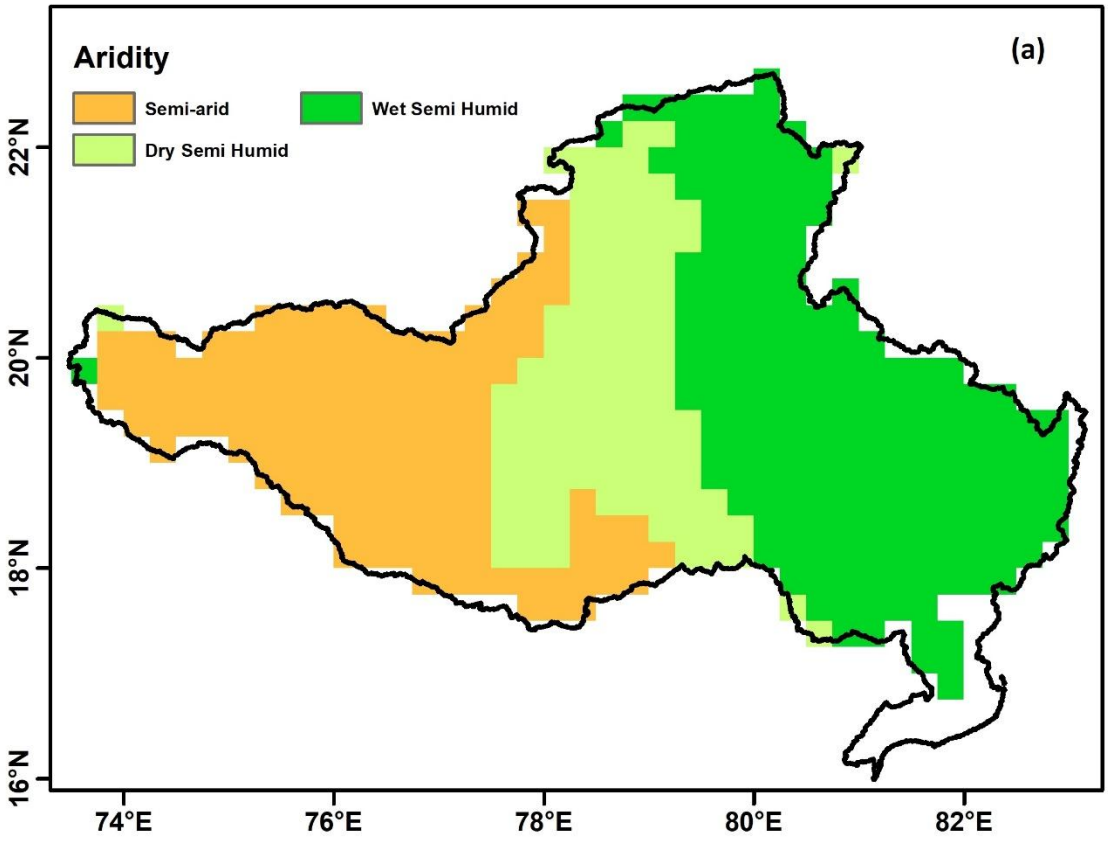

Figure S1. Climatic zones in Godavari Basin using the aridity Index (AI = mean annual

precipitation/mean annual PET). Climate zones are classified as semiarid ($0.2 \leq AI < 0.5$), dry semi-humid ($0.5 \leq AI < 0.65$), and wet semi-humid ($0.65 \leq AI < 1.33$) regions.

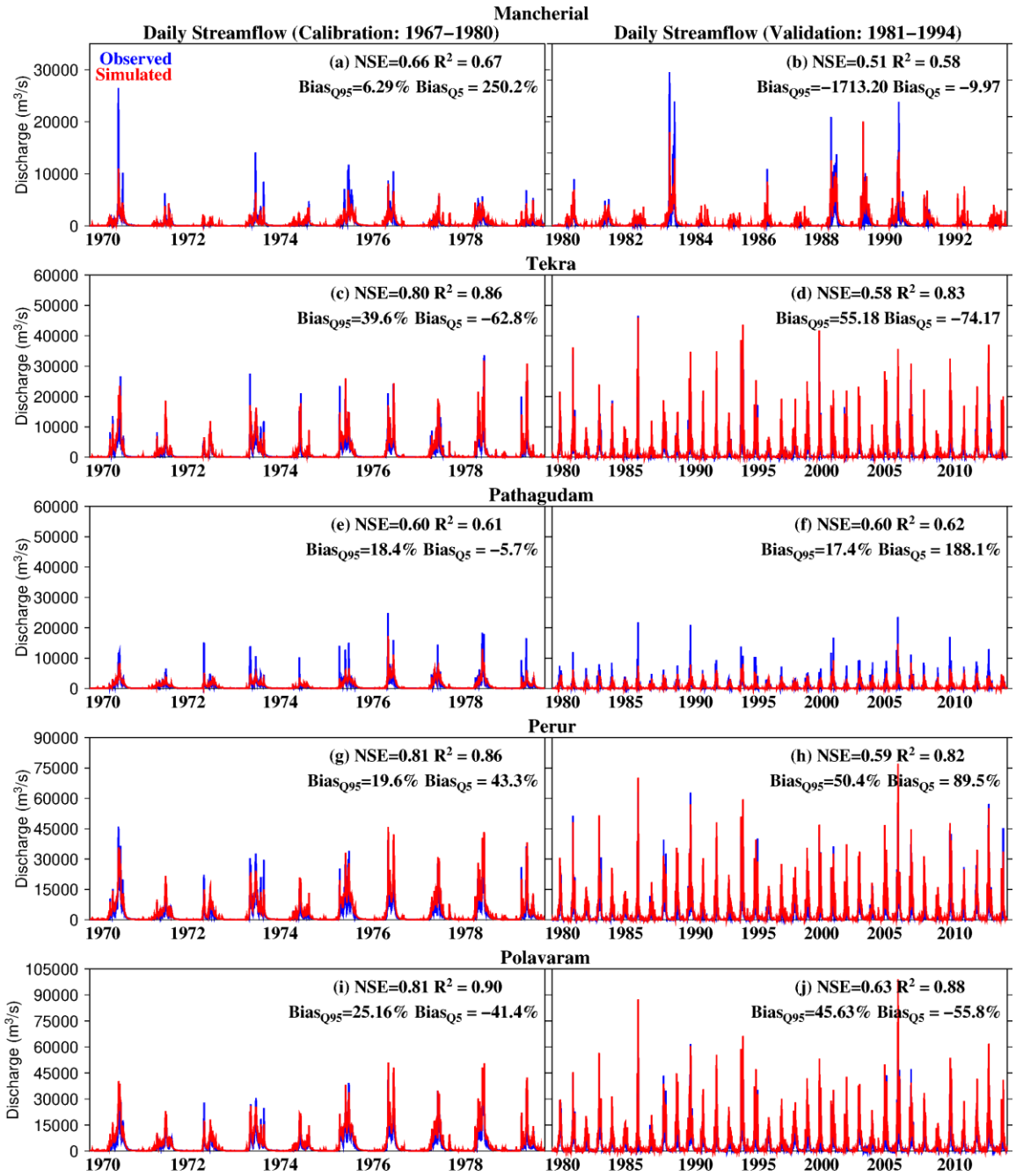

Figure S2. Calibration and validation of the VIC model-simulated streamflow against observed streamflow data at Mancherial, Tekra, Pathagudam, Perur, and Polavaram, for the period 1970-2014. The model was calibrated for the period 1970-1979 and validated for the period 1980-2014 (except for the Mancherial station, which was validated for 1980-1993).

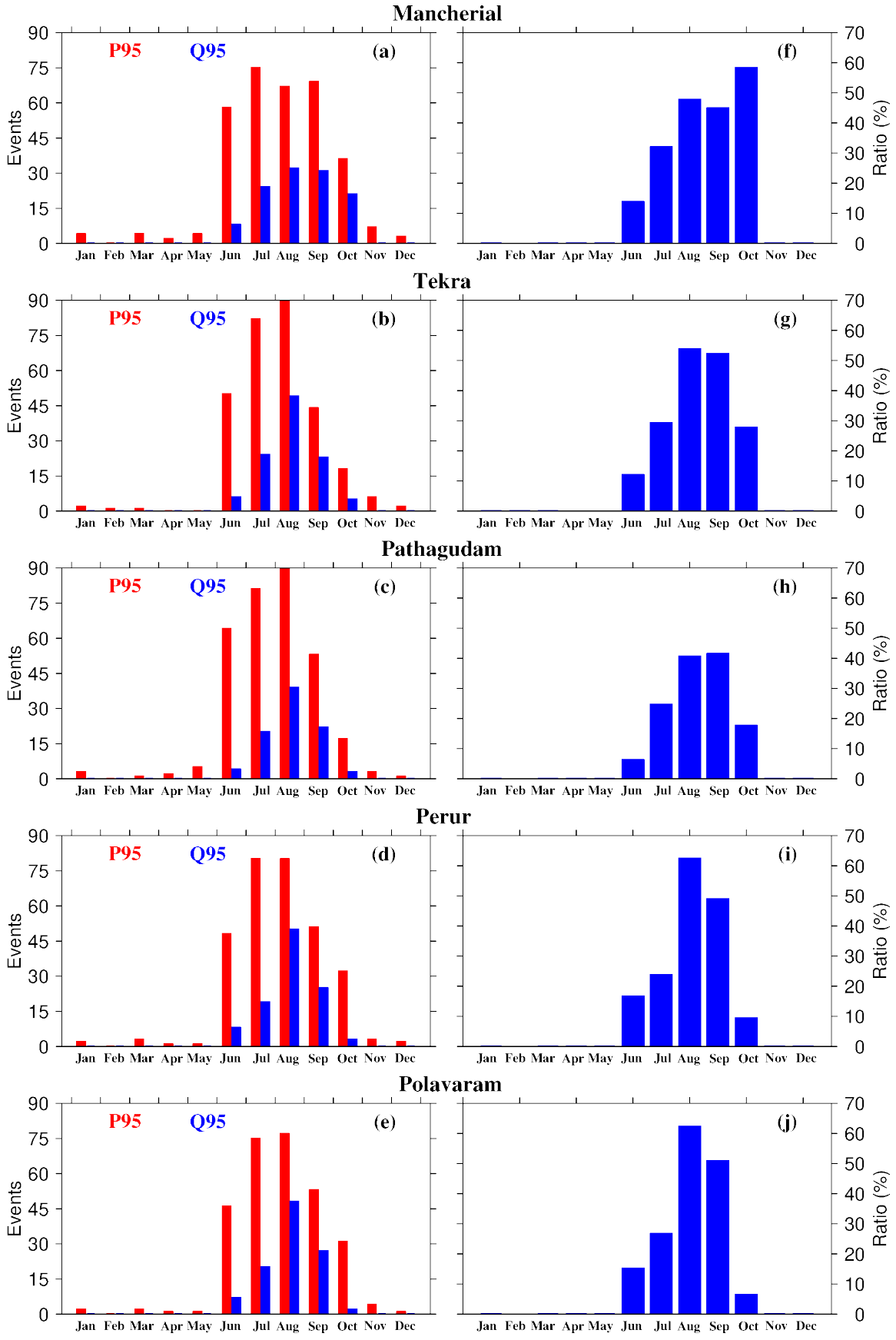
Mancherial
P95
Q95
(a)
(f)
Tekra
(b)
(g)
Pathagudam
(c)
(h)
Perur
(d)
(i)
Polavaram
(e)
(j)
Events
Ratio (%)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure S3. (a-e) Occurrence of high-intensity precipitation (P_{95}) and streamflow (Q_{95}) events (above 95th percentile) during 1967-2019 in each month at (a) Polavaram, (b) Perur, (c) Tekra, (d) Mancherial, and (e) Pathagudam stations. (f-j) Ratio of the number of extreme streamflow and precipitation events in each month at Polavaram, Perur, Tekra, Mancherial, and Pathagudam stations, respectively.

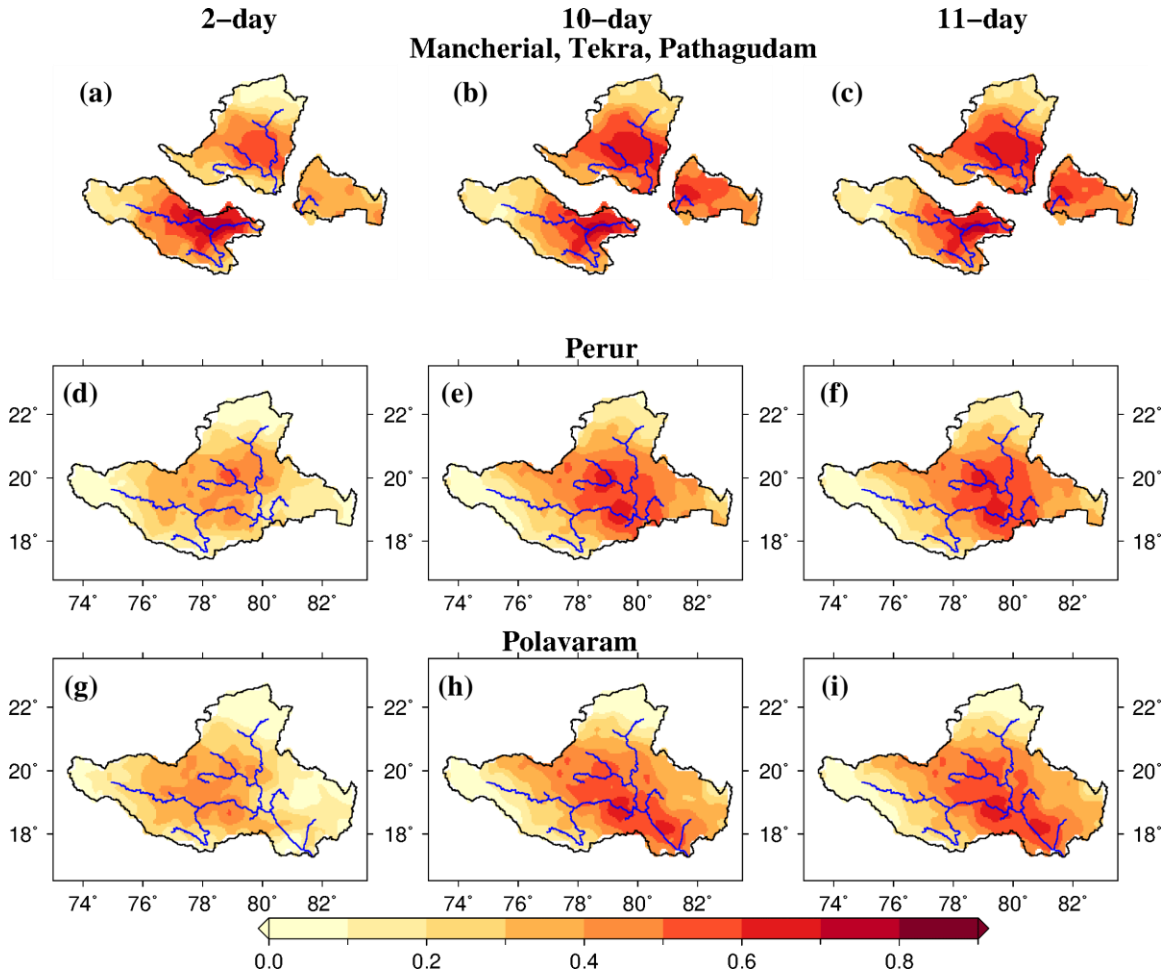

Figure S4. Correlation between upstream accumulated precipitation and high-intensity streamflow at the basin downstream during 1967-2019. (a-c) Correlation between upstream precipitation and high-intensity streamflow at Mancherial (left), Tekra (middle), and Pathagudem (right) sub-basins using (a) 2 days, (b) 10 days, and (c) 11 days cumulative precipitation with 2 days lag period. (d-f) Similar to (a-c) but for Perur sub-basin. (g-i) Similar to (a-c) but for Polavaram.

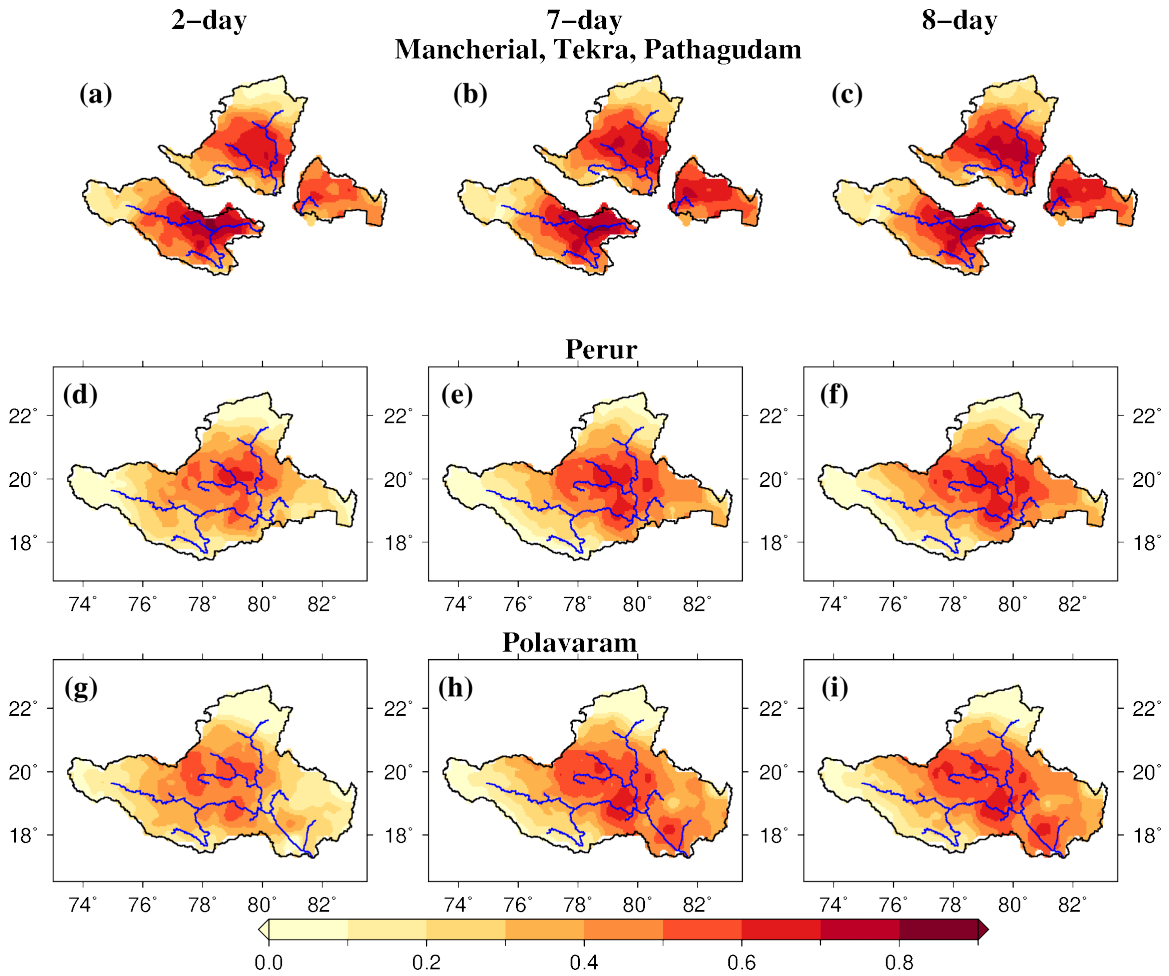

Figure S5. Correlation between runoff and high-intensity streamflow at the basin downstream during 1967-2019. (a-c) Correlation between upstream runoff and high-intensity streamflow at Mancherial (left), Tekra (middle), and Pathagudem (right) sub-basins using (a) 2 days, (b) 7 days, and (c) 8 days cumulative runoff with 2 days lag period. (d-f) Similar to (a-c) but for Perur sub-basin. (g-i) Similar to (a-c) but for Polavaram.

Table S1: Values of performance indices [NSE, Coefficient of determination (R^2), high flow bias (Bias_Q95), low flow bias (Bias_Q5) and bias of the mean (Bias_mean)] during the calibration of VIC simulated discharge (against the observed discharge data) for the period 1970-1979.

Calibration (1970-1979)					
Station	NSE	R^2	Bias_Q95 (%)	Bias_Q5 (%)	Bias_mean (%)
Mancherial	0.66	0.67	6.29	250.21	16.94
Tekra	0.8	0.86	39.57	-62.85	28
Pathagudam	0.6	0.61	18.45	-5.66	17.66
Perur	0.81	0.86	19.59	43.3	35.27
Polavaram	0.81	0.9	25.16	-41.43	37.44

Table S2: Values of performance indices [NSE, Coefficient of determination (R^2), and Bias] during the validation of VIC simulated discharge (against the observed discharge data) for the period 1980-2014 (except Mancherial station; 1980-1993 for Mancherial sub-basin).

Validation (1980-2014)					
Station	NSE	R^2	Bias_Q95 (%)	Bias_Q5 (%)	Bias_mean (%)
Mancherial*	0.52	0.59	88.52	190.3	79.26
Tekra	0.58	0.83	55.18	-74.17	53.76
Pathagudam	0.6	0.62	17.44	188.08	21.47
Perur	0.59	0.82	50.43	89.53	63.7
Polavaram	0.63	0.88	45.63	-55.78	56.37

*validated for 1980-1993

Table S3: Correlations between simulated streamflow peak and basin-averaged accumulated observed precipitation (prior to the flood peak) for different durations (days) and lags (days). The analysis is for high streamflow events at the Mancherial station for the period 1969-2019. Highlighted number is the best correlation value.

Lag / Duration	0	1	2	3	4	5	6	7
1	-0.002	0.248	0.764	0.625	0.386	0.155	0.043	0.154

2	0.190	0.713	0.855	0.626	0.336	0.113	0.112	0.063
3	0.687	0.823	0.852	0.610	0.278	0.150	0.065	0.094
4	0.807	0.823	0.840	0.564	0.287	0.106	0.090	0.105
5	0.806	0.813	0.812	0.553	0.236	0.122	0.099	0.142
6	0.795	0.788	0.803	0.498	0.236	0.127	0.132	0.170
7	0.770	0.786	0.759	0.480	0.230	0.153	0.157	0.183
8	0.768	0.750	0.733	0.461	0.244	0.174	0.170	0.184
9	0.733	0.729	0.711	0.454	0.256	0.186	0.173	0.171
10	0.716	0.711	0.698	0.452	0.264	0.188	0.162	0.208
11	0.700	0.702	0.688	0.451	0.262	0.178	0.198	0.230
12	0.692	0.693	0.683	0.441	0.250	0.211	0.220	0.248
13	0.684	0.689	0.668	0.425	0.278	0.232	0.239	0.266
14	0.681	0.676	0.652	0.442	0.295	0.250	0.257	0.278
15	0.668	0.661	0.659	0.450	0.309	0.268	0.270	0.273
16	0.654	0.669	0.660	0.458	0.324	0.281	0.266	0.265
17	0.661	0.672	0.661	0.466	0.334	0.278	0.260	0.254
18	0.665	0.673	0.660	0.471	0.330	0.272	0.251	0.255
19	0.666	0.672	0.658	0.464	0.325	0.264	0.252	0.248
20	0.666	0.670	0.651	0.459	0.316	0.265	0.245	0.240

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71 Table S4: Same as Table S3 but for the Tekra sub-basin.

Lag / Duration	0	1	2	3	4	5	6	7
1	-0.029	0.238	0.576	0.510	0.178	0.164	0.243	0.252
2	0.152	0.572	0.674	0.473	0.207	0.223	0.290	0.326
3	0.541	0.688	0.649	0.475	0.255	0.291	0.359	0.425
4	0.674	0.662	0.651	0.491	0.319	0.354	0.449	0.467
5	0.648	0.665	0.659	0.521	0.376	0.442	0.483	0.505
6	0.651	0.670	0.681	0.547	0.456	0.476	0.518	0.491
7	0.656	0.693	0.699	0.589	0.487	0.512	0.506	0.483
8	0.680	0.714	0.722	0.607	0.522	0.504	0.499	0.492
9	0.704	0.738	0.725	0.634	0.515	0.501	0.507	0.492
10	0.733	0.739	0.743	0.628	0.513	0.509	0.506	0.458
11	0.735	0.754	0.738	0.620	0.522	0.509	0.475	0.442
12	0.750	0.747	0.728	0.622	0.526	0.484	0.461	0.438
13	0.743	0.738	0.724	0.630	0.504	0.472	0.459	0.422
14	0.733	0.733	0.726	0.614	0.493	0.472	0.444	0.427
15	0.728	0.733	0.711	0.605	0.492	0.459	0.450	0.424
16	0.728	0.719	0.704	0.605	0.481	0.465	0.446	0.418
17	0.713	0.712	0.701	0.595	0.486	0.460	0.439	0.392
18	0.706	0.708	0.691	0.598	0.482	0.454	0.414	0.393
19	0.703	0.697	0.693	0.593	0.475	0.429	0.414	0.411
20	0.693	0.699	0.686	0.585	0.450	0.429	0.429	0.396

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73 Table S5: Same as Table S3 but for the Pathagudam sub-basin.

Duration \ Lag	0	1	2	3	4	5	6	7
1	-0.122	-0.198	0.354	0.485	0.477	0.242	0.152	0.182
2	-0.216	0.275	0.501	0.587	0.444	0.236	0.209	0.254
3	0.257	0.447	0.608	0.599	0.419	0.289	0.283	0.253
4	0.440	0.562	0.641	0.599	0.455	0.352	0.293	0.284
5	0.557	0.602	0.643	0.643	0.497	0.367	0.312	0.326
6	0.594	0.608	0.672	0.674	0.495	0.376	0.351	0.326
7	0.599	0.636	0.706	0.660	0.493	0.414	0.353	0.314
8	0.626	0.668	0.709	0.660	0.520	0.416	0.342	0.288
9	0.658	0.674	0.715	0.678	0.516	0.402	0.317	0.282
10	0.665	0.682	0.731	0.665	0.503	0.379	0.310	0.291
11	0.673	0.700	0.718	0.648	0.482	0.373	0.319	0.290
12	0.694	0.689	0.709	0.632	0.473	0.382	0.321	0.273
13	0.683	0.681	0.702	0.620	0.477	0.383	0.303	0.274
14	0.674	0.674	0.695	0.622	0.479	0.365	0.303	0.277
15	0.668	0.670	0.704	0.627	0.463	0.362	0.306	0.276
16	0.665	0.680	0.714	0.613	0.459	0.363	0.303	0.264
17	0.674	0.691	0.707	0.606	0.457	0.359	0.290	0.249
18	0.686	0.685	0.702	0.603	0.451	0.345	0.275	0.249
19	0.680	0.682	0.703	0.600	0.437	0.326	0.275	0.254
20	0.677	0.686	0.705	0.588	0.418	0.323	0.279	0.265

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75 Table S6. Same as Table S3 but for Perur sub-basin.

Duration \ Lag	0	1	2	3	4	5	6	7
1	-0.054	0.178	0.558	0.544	0.326	0.250	0.207	0.135
2	0.090	0.509	0.651	0.509	0.335	0.263	0.209	0.206
3	0.471	0.637	0.627	0.517	0.346	0.281	0.261	0.292
4	0.617	0.619	0.631	0.523	0.373	0.322	0.330	0.389
5	0.601	0.622	0.636	0.541	0.410	0.377	0.411	0.438
6	0.604	0.626	0.650	0.563	0.456	0.443	0.458	0.433
7	0.609	0.643	0.675	0.591	0.512	0.488	0.454	0.403
8	0.626	0.671	0.699	0.630	0.553	0.486	0.425	0.398
9	0.655	0.699	0.722	0.659	0.547	0.458	0.420	0.393
10	0.685	0.721	0.738	0.651	0.518	0.453	0.415	0.375
11	0.710	**0.735**	0.729	0.624	0.510	0.448	0.398	0.365
12	0.725	0.726	0.705	0.614	0.507	0.431	0.389	0.358
13	0.716	0.704	0.693	0.611	0.490	0.422	0.382	0.343
14	0.695	0.693	0.690	0.595	0.480	0.415	0.368	0.342
15	0.684	0.691	0.678	0.585	0.473	0.402	0.367	0.341
16	0.683	0.680	0.670	0.579	0.460	0.400	0.364	0.339
17	0.671	0.673	0.665	0.570	0.457	0.396	0.362	0.325
18	0.665	0.668	0.659	0.566	0.450	0.393	0.348	0.330
19	0.660	0.664	0.659	0.557	0.446	0.379	0.352	0.349
20	0.656	0.665	0.651	0.550	0.431	0.382	0.369	0.351

Table S7: Same as Table S3 but for the Polavaram sub-basin.

Duration \ Lag	0	1	2	3	4	5	6	7
1	0.084	0.152	0.347	0.613	0.556	0.382	0.182	0.036
2	0.138	0.317	0.573	0.647	0.533	0.344	0.130	0.190
3	0.312	0.551	0.641	0.648	0.511	0.305	0.243	0.263
4	0.544	0.626	0.654	0.637	0.503	0.389	0.307	0.319
5	0.618	0.642	0.649	0.633	0.569	0.426	0.354	0.376
6	0.635	0.637	0.646	0.675	0.600	0.452	0.403	0.408
7	0.631	0.633	0.681	0.702	0.611	0.486	0.435	0.383
8	0.629	0.669	0.705	0.712	0.629	0.510	0.410	0.366
9	0.664	0.696	0.717	0.724	0.636	0.484	0.393	0.350
10	0.692	0.711	0.733	0.727	0.606	0.462	0.378	0.341
11	0.709	0.728	0.739	0.701	0.578	0.446	0.370	0.332
12	0.728	**0.736**	0.719	0.678	0.558	0.437	0.361	0.330
13	**0.736**	0.719	0.699	0.660	0.545	0.426	0.359	0.336
14	0.720	0.700	0.685	0.647	0.533	0.423	0.365	0.341
15	0.702	0.687	0.676	0.637	0.527	0.428	0.370	0.344
16	0.691	0.680	0.668	0.631	0.528	0.430	0.372	0.339
17	0.684	0.673	0.664	0.632	0.528	0.431	0.366	0.329
18	0.678	0.670	0.667	0.631	0.528	0.424	0.356	0.338
19	0.675	0.674	0.668	0.630	0.518	0.413	0.363	0.353
20	0.679	0.676	0.667	0.621	0.504	0.418	0.377	0.354

Table S8. Correlations between simulated streamflow peak and basin-averaged accumulated simulated surface runoff (prior to the flood peak) for different durations (days) and lags (days). The analysis is for high streamflow events at the Mancherial station for the period 1969-2019. The highlighted number is the best correlation value.

Duration \ Lag	0	1	2	3	4	5	6	7
1	0.100	0.368	0.850	0.743	0.485	0.226	0.060	0.232
2	0.340	0.831	0.955	0.750	0.453	0.174	0.177	0.107
3	0.825	0.937	0.960	0.745	0.391	0.239	0.107	0.142
4	0.929	0.943	0.955	0.713	0.421	0.174	0.136	0.169
5	0.935	0.940	0.943	0.719	0.359	0.189	0.155	0.205
6	0.931	0.929	0.943	0.677	0.354	0.201	0.188	0.243
7	0.921	0.934	0.923	0.659	0.351	0.225	0.224	0.264
8	0.925	0.917	0.905	0.647	0.359	0.254	0.245	0.266
9	0.909	0.903	0.896	0.630	0.371	0.272	0.249	0.247
10	0.896	0.895	0.884	0.623	0.383	0.275	0.233	0.288
11	0.889	0.887	0.875	0.620	0.380	0.260	0.275	0.300
12	0.882	0.880	0.871	0.610	0.365	0.296	0.290	0.319
13	0.875	0.876	0.860	0.593	0.391	0.310	0.309	0.334
14	0.872	0.866	0.849	0.599	0.397	0.329	0.325	0.343

15	0.863	0.857	0.847	0.591	0.412	0.344	0.335	0.335
16	0.853	0.857	0.836	0.596	0.422	0.354	0.329	0.326
17	0.852	0.849	0.834	0.598	0.429	0.348	0.322	0.315
18	0.845	0.848	0.829	0.597	0.421	0.342	0.312	0.315
19	0.844	0.843	0.823	0.588	0.416	0.332	0.313	0.310
20	0.840	0.837	0.815	0.583	0.406	0.333	0.308	0.303

Table S9. Same as Table S8 but for the Tekra sub-basin.

Lag / Duration	0	1	2	3	4	5	6	7
1	0.014	0.391	0.774	0.748	0.343	0.224	0.342	0.301
2	0.310	0.775	0.910	0.758	0.339	0.311	0.369	0.395
3	0.762	0.913	0.924	0.747	0.394	0.381	0.447	0.492
4	0.909	0.922	0.928	0.758	0.451	0.449	0.528	0.533
5	0.916	0.929	0.933	0.762	0.505	0.530	0.560	0.561
6	0.922	0.933	0.933	0.767	0.574	0.562	0.581	0.553
7	0.924	0.936	0.937	0.775	0.599	0.588	0.575	0.550
8	0.927	0.943	0.931	0.777	0.621	0.583	0.572	0.560
9	0.937	0.942	0.920	0.784	0.616	0.584	0.580	0.562
10	0.940	0.930	0.917	0.776	0.615	0.591	0.579	0.535
11	0.929	0.925	0.910	0.771	0.624	0.590	0.554	0.515
12	0.924	0.918	0.905	0.769	0.624	0.569	0.536	0.506
13	0.917	0.913	0.897	0.769	0.606	0.554	0.529	0.489
14	0.911	0.905	0.892	0.755	0.590	0.548	0.514	0.497
15	0.902	0.899	0.879	0.741	0.584	0.535	0.522	0.493
16	0.896	0.887	0.867	0.732	0.570	0.542	0.516	0.482
17	0.884	0.875	0.857	0.720	0.576	0.535	0.505	0.466
18	0.873	0.864	0.844	0.718	0.568	0.524	0.490	0.482
19	0.862	0.851	0.841	0.708	0.556	0.509	0.504	0.504
20	0.849	0.848	0.831	0.696	0.541	0.522	0.522	0.478

Table S10. Same as Table S8 but for the Pathagudam sub-basin.

Lag / Duration	0	1	2	3	4	5	6	7
1	-0.059	-0.088	0.528	0.697	0.584	0.289	0.187	0.185
2	-0.102	0.480	0.765	0.758	0.547	0.289	0.229	0.302
3	0.480	0.735	0.851	0.764	0.523	0.335	0.333	0.322
4	0.736	0.834	0.873	0.768	0.549	0.416	0.362	0.365
5	0.836	0.862	0.872	0.799	0.596	0.444	0.391	0.412
6	0.857	0.864	0.887	0.820	0.602	0.459	0.436	0.415
7	0.858	0.877	0.910	0.804	0.602	0.502	0.442	0.404
8	0.870	0.896	0.907	0.800	0.632	0.510	0.433	0.375
9	0.888	0.895	0.905	0.815	0.635	0.501	0.407	0.359
10	0.889	0.893	0.916	0.810	0.627	0.478	0.392	0.364
11	0.887	0.905	0.909	0.802	0.608	0.465	0.396	0.360

12	0.901	0.898	0.907	0.787	0.594	0.468	0.394	0.345
13	0.895	0.897	0.900	0.773	0.592	0.464	0.380	0.351
14	0.894	0.891	0.891	0.768	0.588	0.450	0.384	0.351
15	0.888	0.882	0.892	0.765	0.575	0.450	0.384	0.349
16	0.881	0.884	0.894	0.752	0.572	0.448	0.380	0.334
17	0.882	0.888	0.888	0.747	0.566	0.442	0.364	0.323
18	0.885	0.883	0.882	0.737	0.556	0.424	0.353	0.330
19	0.880	0.878	0.873	0.728	0.539	0.409	0.359	0.337
20	0.875	0.871	0.868	0.713	0.523	0.412	0.364	0.346

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88 Table S11. Same as Table S8 but for the Perur sub-basin.

Lag / Duration	0	1	2	3	4	5	6	7
1	-0.005	0.338	0.742	0.776	0.475	0.323	0.290	0.221
2	0.249	0.724	0.891	0.764	0.470	0.357	0.318	0.290
3	0.714	0.888	0.896	0.766	0.487	0.401	0.368	0.373
4	0.884	0.892	0.900	0.774	0.535	0.440	0.427	0.462
5	0.884	0.896	0.906	0.795	0.563	0.482	0.495	0.508
6	0.888	0.900	0.920	0.791	0.592	0.531	0.537	0.506
7	0.891	0.916	0.930	0.787	0.626	0.572	0.534	0.483
8	0.907	**0.930**	0.924	0.797	0.659	0.571	0.513	0.479
9	0.921	**0.930**	0.917	0.809	0.651	0.551	0.508	0.473
10	0.923	0.923	0.916	0.797	0.629	0.545	0.500	0.452
11	0.917	0.919	0.903	0.778	0.621	0.537	0.480	0.438
12	0.914	0.906	0.889	0.765	0.613	0.517	0.467	0.431
13	0.902	0.894	0.876	0.756	0.592	0.503	0.459	0.416
14	0.889	0.880	0.867	0.736	0.577	0.496	0.446	0.417
15	0.876	0.873	0.853	0.721	0.569	0.483	0.446	0.416
16	0.869	0.860	0.839	0.714	0.556	0.481	0.443	0.408
17	0.855	0.847	0.833	0.703	0.551	0.477	0.435	0.397
18	0.843	0.841	0.824	0.694	0.543	0.468	0.424	0.415
19	0.837	0.833	0.819	0.683	0.532	0.457	0.440	0.439
20	0.829	0.829	0.808	0.669	0.521	0.472	0.461	0.433

89

90 Table S12. Same as Table S8 but for the Polavaram sub-basin.

Lag / Duration	0	1	2	3	4	5	6	7
1	0.132	0.310	0.532	0.857	0.692	0.443	0.279	0.149
2	0.274	0.523	0.845	0.865	0.658	0.441	0.258	0.281
3	0.531	0.833	0.895	0.853	0.657	0.439	0.360	0.343
4	0.829	0.884	0.888	0.855	0.681	0.513	0.403	0.397
5	0.877	0.880	0.891	0.869	0.736	0.524	0.446	0.451
6	0.875	0.882	0.904	0.890	0.738	0.546	0.487	0.480
7	0.877	0.894	0.923	0.890	0.738	0.573	0.515	0.459
8	0.891	0.915	0.920	0.882	0.740	0.593	0.495	0.447

9	0.910	0.917	0.913	0.876	0.737	0.571	0.482	0.438
10	0.914	0.913	0.910	0.865	0.713	0.554	0.473	0.426
11	0.912	0.912	0.902	0.846	0.693	0.544	0.461	0.416
12	0.913	0.906	0.888	0.830	0.677	0.532	0.450	0.411
13	0.907	0.893	0.874	0.815	0.660	0.520	0.445	0.416
14	0.895	0.880	0.862	0.798	0.646	0.513	0.450	0.419
15	0.882	0.869	0.850	0.785	0.636	0.516	0.452	0.422
16	0.872	0.857	0.840	0.776	0.635	0.516	0.454	0.416
17	0.861	0.849	0.832	0.773	0.631	0.516	0.446	0.407
18	0.853	0.842	0.829	0.766	0.629	0.507	0.437	0.425
19	0.846	0.839	0.824	0.763	0.617	0.497	0.453	0.447
20	0.845	0.835	0.820	0.751	0.605	0.511	0.473	0.442