

# Two-Stage Spatiotemporal Time Series Modelling Approach for Rice Yield Prediction & Advanced Agroecosystem Management

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Table S1. Descriptive statistics of rice yield (kg/ha) data across the examined area, Andhra Pradesh, India

Districts	Mean	Standard Deviation	Maximum	Minimum	CV (%)
Srikakulam	2445.10	755.86	4459.00	1749.00	30.91
Vizianagaram	3213.55	1238.98	5697.00	1788.00	38.55
Visakhapattanam	2909.07	793.48	5101.00	1991.00	27.28
Godavari_East	3534.45	1154.51	6000.00	2127.00	32.66
Godavari_West	3029.26	947.91	5421.00	1841.00	31.29
Krishna	3905.93	1406.61	6924.00	2239.00	36.01
Guntur	3632.51	1113.45	5783.00	2233.00	30.65
Prakasam	3670.12	1128.98	6279.00	2521.40	30.76
Nellore	3659.06	1190.50	6318.00	2585.00	32.54
YSR	3798.00	1352.61	6705.00	2347.00	35.61
Karnool	3925.21	1288.62	6723.00	2489.00	32.83
Ananthpuramu	2675.03	906.94	4829.00	1434.00	33.90
Chittoor	1829.37	703.20	3614.00	1076.00	38.44

Table S2. Coordinate matrix for districts of A.P. India

District	Longitude	Latitude
Srikakulam	83.89°E	18.29°N
Vizianagaram	83.39°E	18.1°N
Visakhapattanam	83.21°E	17.68°N
Godavari_East	82.04°E	17.32°N
Godavari_West	81.33°E	16.91°N
Krishna	80.72°E	16.61°N
Guntur	80.43°E	16.3°N
Prakasam	79.56°E	15.34°N
Nellore	79.98°E	14.44°N
YSR	78.72°E	14.46°N
Karnool	78.03°E	15.82°N
Ananthpuramu	77.6°E	14.68°N
Chittor	79.1°E	13.21°N

Table S3. Nearest neighbours for each districts of A.P. India

District	Nearest neighbour
Srikakulam	Vizainagaram
Vizianagaram	Visakhapattanam
Visakhapattanam	Vizainagaram
Godavari_East	Godavari_West
Godavari_West	Krishna
Krishna	Guntur
Guntur	Krishna
Prakasam	Nellore
Nellore	Prakasam
YSR	Ananthpuramu
Karnool	Ananthpuramu
Ananthpuramu	YSR
Chittor	YSR

Table S4. Zero order weight matrix among examined districts

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
D1	1	0	0	0	0	0	0	0	0	0	0	0	0
D2	0	1	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	1	0	0	0	0	0	0	0	0	0	0
D4	0	0	0	1	0	0	0	0	0	0	0	0	0
D5	0	0	0	0	1	0	0	0	0	0	0	0	0
D6	0	0	0	0	0	1	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	1	0	0	0	0	0	0
D8	0	0	0	0	0	0	0	1	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	1	0	0	0	0
D10	0	0	0	0	0	0	0	0	0	1	0	0	0
D11	0	0	0	0	0	0	0	0	0	0	1	0	0
D12	0	0	0	0	0	0	0	0	0	0	0	1	0
D13	0	0	0	0	0	0	0	0	0	0	0	0	1

D1 to D13 indicates different districts considered D1: Srikakulam, D2: Vizainagaram, D3: Visakhapattanam, D4: Godavari\_East, D5: Godavari\_West, D6: Krishna, D7: Guntur, D8: Prakasam, D9: Nellore, D10: YSR, D11: Karnool, D12: Ananthpuramu, D13: Chittor

Table S5: First order uniform spatial weight matrix

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
D1	0	1	0	0	0	0	0	0	0	0	0	0	0
D2	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0
D3	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0
D4	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0
D5	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0
D6	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0
D7	0	0	0	0	0	0.5	0	0.5	0	0	0	0	0
D8	0	0	0	0	0	0	0.25	0	0.25	0.25	0.25	0	0
D9	0	0	0	0	0	0	0	0.33	0	0.33	0	0	0.33
D10	0	0	0	0	0	0	0	0.2	0.2	0	0.2	0.2	0.2
D11	0	0	0	0	0	0	0	0.33	0	0.33	0	0.33	0
D12	0	0	0	0	0	0	0	0	0	0.33	0.33	0	0.33
D13	0	0	0	0	0	0	0	0	0.33	0.33	0	0.33	0

D1 to D13 indicates different districts considered D1: Srikakulam, D2: Vizainagaram, D3: Visakhapattanam, D4: Godavari\_East, D5: Godavari\_West, D6: Krishna, D7: Guntur, D8: Prakasam, D9: Nellore, D10: YSR, D11: Karnool, D12: Ananthpuramu, D13: Chittor

Table S6: Second order uniform spatial weight matrix

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
D1	0	0.5	0.5	0	0	0	0	0	0	0	0	0	0
D2	0.33	0	0.33	0.33	0	0	0	0	0	0	0	0	0
D3	0.25	0.25	0	0.25	0.25	0	0	0	0	0	0	0	0
D4	0	0.25	0.25	0	0.25	0.25	0	0	0	0	0	0	0
D5	0	0	0.25	0.25	0	0.25	0.25	0	0	0	0	0	0
D6	0	0	0	0.25	0.25	0	0.25	0.25	0	0	0	0	0
D7	0	0	0	0	0	0.17	0	0.17	0.17	0.17	0.17	0	0
D8	0	0	0	0	0	0.14	0.14	0	0.14	0.14	0.14	0.14	0.14
D9	0	0	0	0	0	0	0.17	0.17	0	0.17	0.17	0.17	0.17
D10	0	0	0	0	0	0	0.17	0.17	0.17	0	0.17	0.17	0.17
D11	0	0	0	0	0	0	0.17	0.17	0.17	0.17	0	0.17	0.17
D12	0	0	0	0	0	0	0.17	0.17	0.17	0.17	0.17	0	0.17
D13	0	0	0	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0

D1 to D13 indicates different districts considered D1: Srikakulam, D2: Vizainagaram, D3: Visakhapattanam, D4: Godavari\_East, D5: Godavari\_West, D6: Krishna, D7: Guntur, D8: Prakasam, D9: Nellore, D10: YSR, D11: Karnool, D12: Ananthpuramu, D13: Chittor

Table S7: Third order uniform spatial weight matrix

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
D1	0	0.33	0.33	0.33	0	0	0	0	0	0	0	0	0
D2	0.25	0	0.25	0.25	0.25	0	0	0	0	0	0	0	0
D3	0.2	0	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
D4	0.17	0.17	0.17	0	0.17	0.17	0.17	0	0	0	0	0	0
D5	0	0.17	0.17	0.17	0	0.17	0.17	0.17	0	0	0	0	0
D6	0	0	0.14	0.14	0.14	0	0.14	0.14	0.14	0.14	0	0	0
D7	0	0	0	0.11	0.11	0.11	0	0.11	0.11	0.11	0.11	0.11	0.11
D8	0	0	0	0	0.12	0.12	0.12	0	0.12	0.12	0.12	0.12	0.12
D9	0	0	0	0	0	0.14	0.14	0.14	0	0.14	0.14	0.14	0.14
D10	0	0	0	0	0	0.14	0.14	0.14	0.14	0	0.14	0.14	0.14
D11	0	0	0	0	0	0.14	0.14	0.14	0.14	0.14	0	0.14	0.14
D12	0	0	0	0	0	0	0.17	0.17	0.17	0.17	0.17	0	0.17
D13	0	0	0	0	0	0	0.17	0.17	0.17	0.17	0.17	0.17	0

D1 to D13 indicates different districts considered D1: Srikakulam, D2: Vizainagaram, D3: Visakhapattanam, D4: Godavari\_East, D5: Godavari\_West, D6: Krishna, D7: Guntur, D8: Prakasam, D9: Nellore, D10: YSR, D11: Karnool, D12: Ananthpuramu, D13: Chittor

Table S8. TDNN model parameter specifications for STARMA ( $\phi_{10}, \phi_{11}, \theta_{11}$ ) residuals series

District	Parameters	
Srikakulam	2-4-1 Networks, 17 Weights	TDNN(2,4)
Vizianagaram	2-3-1 Networks, 13 Weights	TDNN(2,3)
Visakhapattanam	1-3-1 Networks, 10 Weights	TDNN (1,3)
Godavari_East	1-4-1 Networks, 13 Weights	TDNN (1,4)
Godavari_West	1-4-1 Networks, 13 Weights	TDNN (1,4)
Krishna	2-4-1 Networks, 17 Weights	TDNN (2,4)
Guntur	1-3-1 Networks, 10 Weights	TDNN (1,3)
Prakasam	2-3-1 Networks, 13 Weights	TDNN (2,3)
Nellore	1-4-1 Networks, 13 Weights	TDNN (1,4)
YSR	2-3-1 Networks, 13 Weights	TDNN (2,3)
Karnool	2-4-1 Networks, 13 Weights	TDNN (2,3)
Ananthpuramu	2-3-1 Networks, 13 Weights	TDNN (2,3)
Chittoor	2-3-1 Networks, 13 Weights	TDNN (2,3)

Table S9a: Out of sample forecasts obtained by different methods

Year	Srikakulam				Vizianagaram			
	Actual	Forecast			Actual	Forecast		
		ARIMA	STARMA	STARMA-II		ARIMA	STARMA	STARMA-II
2016-17	4459	2195.43	3503.38	5345.81	4556	2297.62	4078.12	4470.03
017-18	3795	2195.43	3754.46	3904.23	4479	2297.62	4029.22	4470.03
2018-19	3117	2195.43	2520.25	3450.88	3540	2297.62	4211.23	4470.038
2019-20	4277	2195.43	3490.58	4819.53	4829	2297.62	4268.22	4470.03
Year	Visakhapattanam				Godavari_East			
	Actual	Forecast			Actual	Forecast		
		ARIMA	STARMA	STARMA-II		ARIMA	STARMA	STARMA-II
2016-17	3365	1659.9	2710.34	2926.4	6356	3966	5587.5	5777.56
2017-18	3150	1659.9	2765.66	2979.03	6491	3966	5538.2	5711.78
2018-19	2568	1659.9	2893.41	2708.53	6705	3966	5976.14	6108.58
2019-20	3614	1659.9	2887.44	3061.8	6318	3966	6002.11	6018.22
Year	Godavari_West				Krishna			
	Actual	Forecast			Actual	Forecast		
		ARIMA	STARMA	STARMA-II		ARIMA	STARMA	STARMA-II
2016-17	6257	4071	5353.35	5897.56	5819	3149.61	5169.32	5521.58
2017-18	6461	4071	5317.97	5911.78	5983	3149.61	5296.75	5611.29
2018-19	6594	4071	5829.65	6108.58	6279	3149.61	5590.66	5789.44
2019-20	6723	4071	6001.28	6298.22	6006	3149.61	5598.74	5797.55
Year	Guntur				Prakasam			

	Nellore				YSR			
	Actual	Forecast			Actual	Forecast		
Year		ARIMA	STARMA	STARMA-II		ARIMA	STARMA	STARMA-II
2016-17	6271	3277.05	5342.35	5387.25	5386	3131.78	4282.47	4889.96
2017-18	6318	3217.1	5447.76	5508.96	5752	3131.78	4724.77	5239.8
2018-19	5950	3277.05	5585.63	5686.33	5254	3131.78	4912.35	5684.76
2019-20	5977	3217.1	5589.66	5601.88	5658	3131.78	5228.99	5718.41

Table S9b: Out of sample forecasts obtained by different methods

Year	Karnool				Ananthpuramu			
	Actual	Forecast			Actual	Forecast		
		ARIMA	STARMA	STARMA-II		ARIMA	STARMA	STARMA-II
2016-17	6000	3053.78	4577.21	4852.77	3764	2613.63	3317.68	3955.56
2017-18	5326	3053.78	4655.47	4958.32	4190	2613.63	3269.82	3866.32
2018-19	5746	3053.78	4980.27	5789.87	3933	2613.63	3689.54	4690.87
2019-20	5942	3053	5455.23	5888.98	5101	2613.63	4186.33	4670.28

  

Year	Chittoor			
	Actual	Forecast		
		ARIMA	STARMA	STARMA-II
2016-17	5467	2667.04	4478.76	4855.65
2017-18	5697	2667.04	4735.18	4983.82
2018-19	5454	2667.04	4856.47	5093.12
2019-20	5513	2667.04	4887.66	5158.88