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Supplementary materials

Near real-time biophysical rice modeling to support crop insurance implementation in India.

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Table S1. The states and their acronyms of the study area. The symbol * represents the selected states for this study, according to data availability (see below).

State	Code	State	Code	State	Code
Andaman and Nicobar	AN	Himachal Pradesh	HP *	Puducherry	PY
Andhra Pradesh	AP *	Jammu and Kashmir	J &K	Punjab	PU *
Arunachal Pradesh	ARNP	Jharkhand	JH *	Rajasthan	RJ *
Assam	AS	Karnataka	KA *	Sikkim	SI
Bihar	BH *	Kerala	KL *	Tamil Nadu	TN *
Chandigarh	CH	Lakshadweep	LD	Telangana	TL *
Chhattisgarh	CHT *	Madhya Pradesh	MP *	Tripura	TR
Dadra and Nagar Haveli	DADN	Maharashtra	MH *	Uttar Pradesh	UP *
Daman and Diu	DADI	Manipur	MN	Uttarakhand	UK *
Delhi	DL	Meghalaya	MG	West Bengal	WB *
Goa	GA	Mizoram	MZ		
Gujarat	GJ *	Nagaland	NL		
Haryana	HR *	Orissa	OR *		

Table S2. The varieties and calibrated genetic coefficients were used in this study.

Varieties/Genetic Coefficients	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT	G5
Swarna	580	165	506	11.3	75	0.023	1	1	83	1
MTU-7029	740	115	11	330	68	0.025	1	1	83	1
Sarjoo52	450	170	365	12.2	47	0.0238	1	0.8	83	1
Pusa-sugangh-3	550	105	550	14	40	0.024	1	1	83	1
IET-6223	400	110	12	310	58.5	0.024	1	1	83	1
JAYA	830	100	200	11.4	40	0.03	1	0.8	83	1
Satabdi	650	80	300	13.1	56	0.225	0.7	1	83	1
NDR-359	600	150	410	12	42	0.02	1	0.8	83	1
MTU-1075	680	120	11.2	340	62.5	0.023	1	1	83	1
Pusa-sugangh-4	550	150	550	12	40	0.024	1	1	83	1
Kranti	830	140	12	250	45	0.025	0.8	1	83	1
MTU1010	425	135	250	11.6	62	0.022	1	1	83	1
IR36_1	470	50	350	11.7	65	0.02	0.9	1	83	1
IR 66	500	50	490	12.5	62	0.0265	1	1	83	1
Sharbati	780	90	400	15.4	60	0.022	0.7	0.8	83	1
Karma-mahsuri	478	150	364	11.5	113	0.029	1	1	83	1
ASD-16	470	149	400	11.7	55.3	0.025	1	1	83	1
ADT-43	357	61	448	11.9	50.8	0.023	0.4	1	83	1
IR 72x	400	100	580	12	76	0.023	1	1	83	1
NDR-97	385	85	448	11.9	52	0.022	1	1	83	1
IET-4461	420	100	11.4	360	51	0.021	1	1	83	1
Swarna1	620	180	490	11.8	70	0.02	0.9	1	83	1
Mahamaya	429	150	302	11.5	56	0.025	1	1	83	1

IR 43	720	120	580	10.5	65	0.028	1	1	83	1
IR 8	880	52	550	12.1	65	0.028	1	1	83	1
IR 64	500	160	450	12	60	0.025	1	1	83	1
IR 36	470	149	400	11.7	68	0.023	1	1	83	1
Swarna2	640	180	520	11.6	67	0.02	0.9	1	83	1
IR 54	350	125	520	11.5	60	0.028	1	1	83	1

Note:

	DSSAT default cultivars
	Genetic coefficients modified cultivars and cultivars from literature
	Cultivars derived from Agromet Field Units (India) AMFU

P1 - Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.

P2O - Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O developmental rate is slowed, hence there is a delay due to longer day lengths.

P2R - Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.

P5 - The time period in GDD °C) from the beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.

G1 - Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55.

G2 - Single grain weight (g) under ideal growing conditions, i.e., nonlimiting light, water, nutrients, and absence of pests and diseases.

G3 - Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have a coefficient greater than 1.0.

G4 - Temperature tolerance coefficient. Usually, 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice is very cool environments or season would be less than 1.0.

Table S3. The parameters used for analyzing the assessment of goodness index

Statistical parameter	Formula	Reference
Relative Root Mean Square Error (rRMSE)	$\sqrt{\frac{1}{n}\sum(P_i - O_i)^2}$	(Balkovič et al., 2013)
The index of agreement(d)	$1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}\right]$	(Willmott, 1981)
Pearson's correlation coefficient (r)	$\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - \bar{P})^2}}$	(Sedgwick, 2012)
Pearson's correlation coefficient of determination (R2)	$\left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right)^2$	(Kvålseth, 1985)

Note: Pi – Time-series simulated yield anomaly; Oi – Time-series observed yield anomaly; n– Number of time series; $\bar{O}$ is the mean of the observed yields

Table S4. The state-wise information on inputs such as varieties used, sowing date, and irrigation status over the pixels within the state after the calibration

State	Varieties used	Sowing date	Irrigation
Andhra Pradesh	Swarna1, Swarna, JAYA, IR 72x, Mahamaya, IR 64, Sharbati, Karma, mahsuri, IR 54, Pusa-sugangh-3	175 195	Rainfed - 17% Irrigated – 83%
Bihar	Pusa-sugangh-4	165	Rainfed – 100%
Chhattisgarh	Sarjoo52, Pusa-sugangh-3, IR36_1, MTU1010, NDR-359, ADT-43, IR 43, Mahamaya, ASD-16, IR 64, NDR-97, Swarna1, Karma-mahsuri	175 195 160	Irrigated – 100%
Gujarat	NDR-359, MTU1010, Swarna, Sarjoo52, IET-6223, ADT-43, IR36_1, Pusa-sugangh-3, Satabdi, Mahamaya, NDR-97, JAYA	160 175 195	Irrigated – 100%
Haryana	Satabdi, NDR-97, IR36_1, JAYA, ADT-43, IR 66, IR 72x, Sarjoo52, NDR-359	175 160 195	Irrigated – 100%

Himachal Pradesh	Swarna, MTU-7029, Sarjoo52, Pusa-sugangh-3, IET-6223, JAYA, Satabdi, NDR-359, MTU-1075, Pusa-sugangh-4, Kranti, MTU1010, IR36_1, IR 66, Sharbati, Karma-mahsuri, ASD-16, ADT-43, IR 72x, NDR-97, IET-4461, Swarna1, Mahamaya, IR 43, IR 8, IR 64, IR 36, Swarna2, IR 54	175 195	Irrigated – 100%
Jharkhand	Swarna, NDR-359, ADT-43, Pusa-sugangh-3, Satabdi, MTU-7029	175 195	Rainfed - 3% Irrigated – 97%
Karnataka	Pusa-sugangh-3, MTU-1075, NDR-359, Pusa-sugangh-4, Sarjoo52, IR36_1, IR 66, Kranti, NDR-97, Swarna1, MTU1010, IR 54, IR 36, IR 72x, ADT-43, ASD-16	175 195 160	Rainfed - 3% Irrigated – 97%
Kerala	IR 72x, Swarna, IR36_1, IR 66, Sharbati, Pusa-sugangh-4	175	Irrigated – 100%
Madhya Pradesh	IR 66, JAYA, Satabdi, IR36_1, IET-4461, Kranti, NDR-359, Swarna1, Pusa-sugangh-3, IET-6223, MTU-1075, ASD-16	175 160 195	Rainfed - 2% Irrigated – 98%
Maharashtra	JAYA, Pusa-sugangh-3, NDR-359, Satabdi, IET-6223, Swarna, MTU-1075, IR 66, Mahamaya, Sarjoo52, IR 72x, Swarna2	175 160 195	Rainfed - 1% Irrigated – 99%
Orissa	Pusa-sugangh-3, IR36_1, Swarna, ADT-43, MTU1010, IR 8, NDR-359, Swarna1	195 175 160	Irrigated – 100%
Punjab	JAYA, NDR-359, Pusa-sugangh-3, Pusa-sugangh-4, MTU1010, IR36_1, IR 66, Sharbati, Karma-mahsuri, Swarna, IR 72x, ASD-16	175 160 195	Rainfed - 4% Irrigated – 96%
Rajasthan	IR 72x, IR 66, Pusa-sugangh-3, ADT-43, NDR-97, Satabdi	175 160	Rainfed - 3% Irrigated – 97%
Tamil Nadu	IR 54, Pusa-sugangh-4, Pusa-sugangh-3, IR36_1, Swarna2, Mahamaya, Karma-mahsuri, Swarna, Swarna1, Sharbati, IR 36, IR 8, MTU-7029	175 195 160	Rainfed - 20% Irrigated – 80%

Telangana	Sarjoo52, ASD-16, Pusa-sugangh-3, IR 66, Mahamaya, IR36_1, IR 36	175 160	Rainfed - 22% Irrigated – 78%
Uttar Pradesh	MTU1010, Pusa-sugangh-4, Pusa-sugangh-3, IR36_1, NDR-97, NDR-359, Sarjoo52, JAYA, ADT-43, Satabdi, MTU-7029, MTU-1075, Kranti	160 175 195	Irrigated – 100%
Uttarakhand	IR36_1, ADT-43, NDR-97, JAYA, Satabdi, Pusa, sugangh-3, MTU1010	195 175 160	Irrigated – 100%
West Bengal	NDR-359, Pusa-sugangh-4, Swarna, Satabdi, ADT-43, IR36_1, JAYA, NDR-97, Sarjoo52	175 160	Irrigated – 100%

Table S5: State-wise average of RMSE and d which explains the goodness index of simulated yield loss with observed yield loss

State	RMSE	d
Andhra Pradesh	19.7	0.4
Bihar	54.1	0.2
Chhattisgarh	32.4	0.4
Gujarat	27.6	0.4
Haryana	18.4	0.4
Himachal Pradesh	27.8	0.4
Jharkhand	53.7	0.3
Karnataka	23.3	0.4
Kerala	31.5	0.2
Madhya Pradesh	54.5	0.3
Maharashtra	34.7	0.4
Orissa	27.4	0.3
Punjab	19.6	0.4
Rajasthan	34.9	0.5
Tamil Nadu	31.0	0.4
Telangana	17.3	0.3

Uttar Pradesh	20.9	0.4
Uttarakhand	14.5	0.4
West Bengal	10.6	0.5

The spatial distribution maps Figure S7 shows the simulated yield from the calibrated model for the Kharif season of 2016 and 2017. The calibrated model simulated the yield for Kharif 2016 and 2017, which follows a similar pattern of the long-term (2001-2015) average of observed yields. The pattern of simulated yields explains there was not much change in the yields of Kharif Rice in 2016 and 2017, which also explained that these are years are a good year.

Table S6: The state-wise observed and simulated yield information for the Kharif 2016 and 2017. The unit of the data is kg/ha

	KHARIF – 2016			KHARIF - 2017			Average yield
State	Observed	Simulated	Yield difference	Observed	Simulated	Yield difference	2001-2015
Andhra Pradesh	3453	2769	683	No Data	No Data	No Data	2782
Gujarat	2191	1720	471	1895	1840	55	1697
Karnataka	2481	2549	-68	2791	2563	227	2540
Maharashtra	1930	1411	519	No Data	No Data	No Data	1398
Punjab	4032	3465	566	4184	3564	619	3752
Rajasthan	2344	1998	346	No Data	No Data	No Data	2030
Tamil Nadu	3092	3391	-298	No Data	No Data	No Data	3472
Telangana	3160	2730	430	No Data	No Data	No Data	2833
Uttar Pradesh	2405	2109	296	No Data	No Data	No Data	2170
Uttarakhand	1811	1598	212	1888	1558	330	1659
Himachal Pradesh	No Data	No Data	No Data	1830	1397	433	1715

Table S6 provides information on actual yields of observed and simulate for Kharif 2016 and 2017 as well as the long term average of observed time series. All the simulated yields are very close to observed long term average, and simulated yields produce <500 kg of yield difference with observed yields of Kharif 2016 and 2017 except Andhra Pradesh, Maharashtra, and Punjab. Andhra Pradesh and Maharashtra yields can be an outlier as simulated yields are close to long-term observed yield. However, 14% of yield loss on higher yields like >4000 kg/ha produces more than 500 kg of error like the state Punjab.

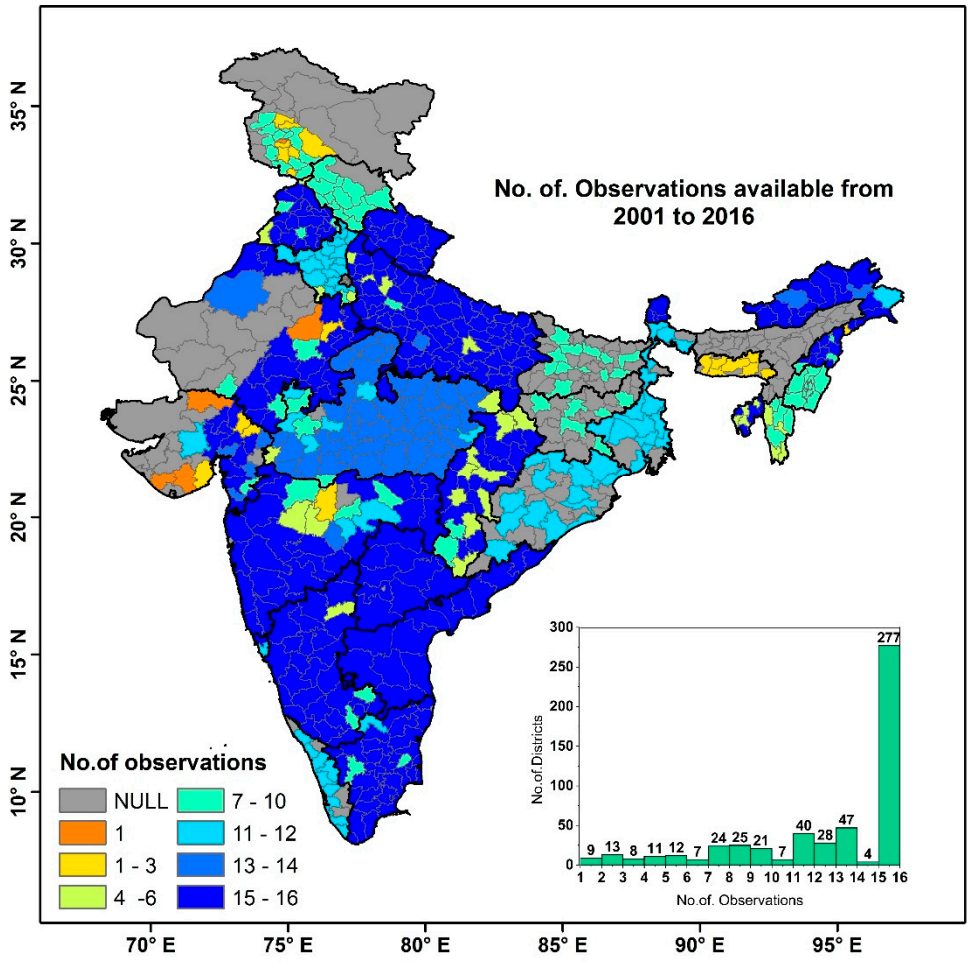

Figure S1: The number of observations available from DES district level yields between 2001 and 2016 for Kharif rice.

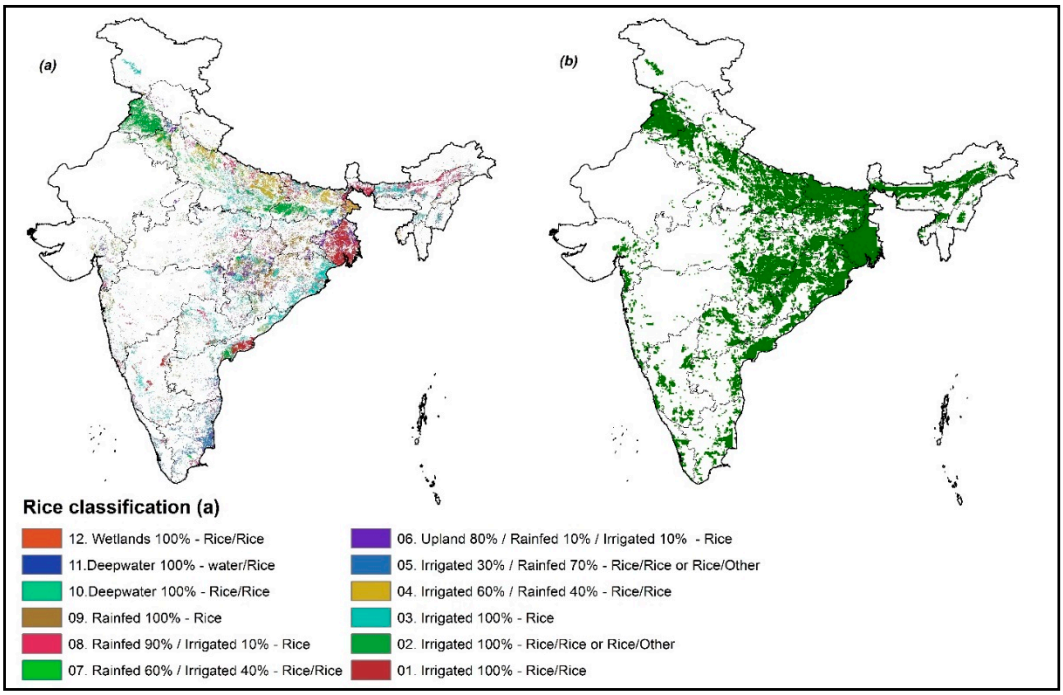

Figure S2: The spatial distribution map for rice mask from very high-resolution MODIS multispectral rice classification, and derived 0.05° spatial resolution crop mask. a. Rice distribution under various irrigation types such as wetlands, deep water, upland, Irrigated, and rainfed. The crop names show the crop rotation (i.e., "Rice/Rice" means rice grows over the pixel both seasons (Kharif/Rabi)). b. Derived rice area distribution map in 5km resolution, based on the MODIS data in a map (a).

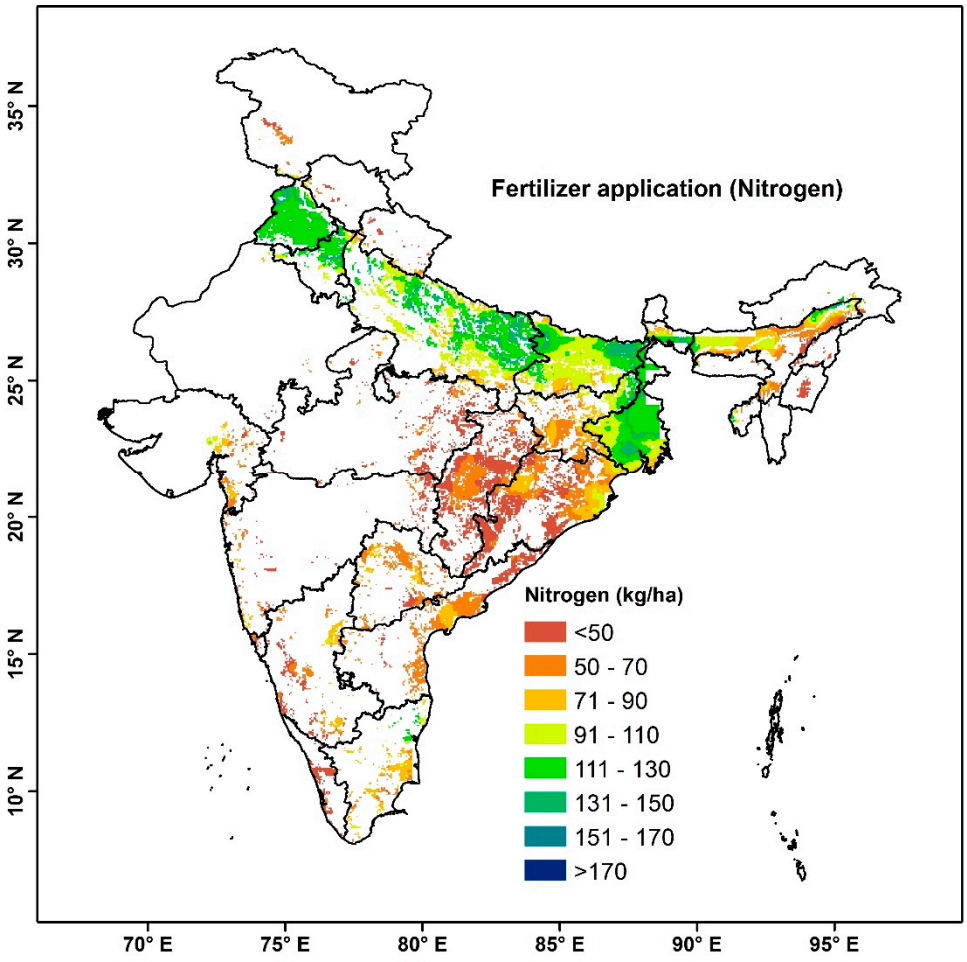

Figure S3: Map of the fertilizer (N) application for Kharif rice in India

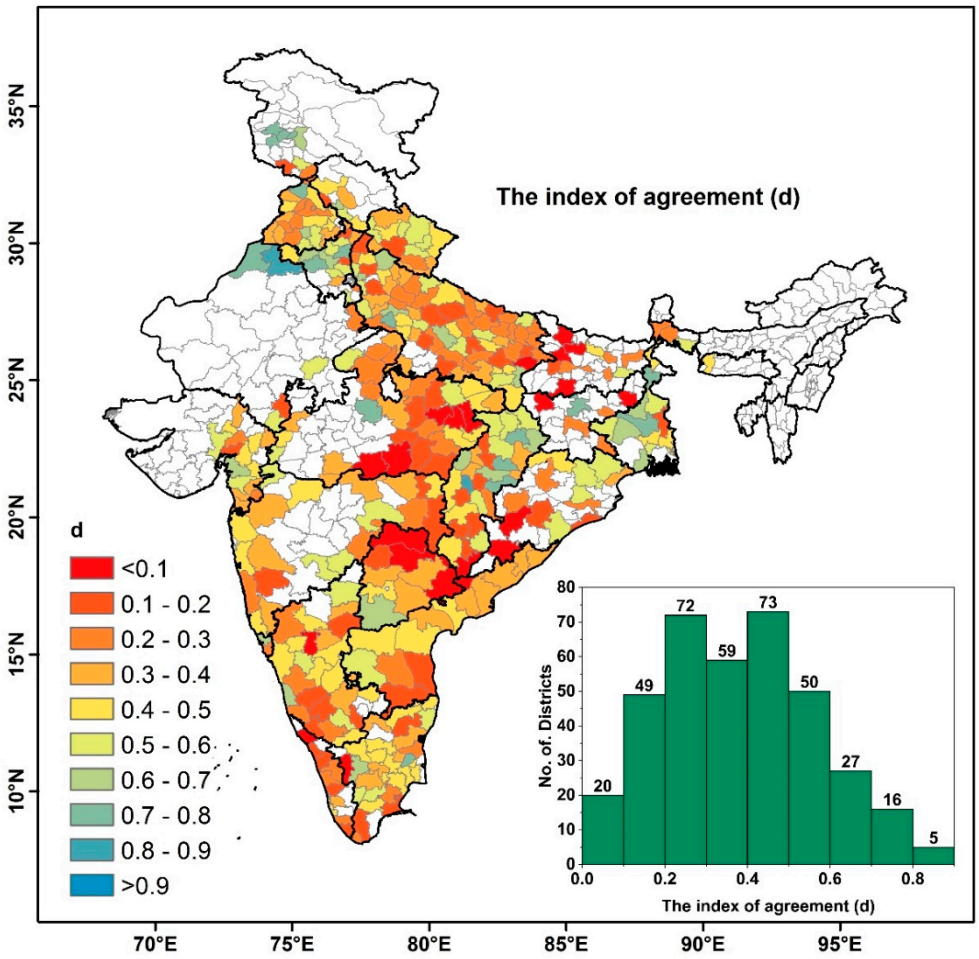

Figure S4: District-specific d values and histogram of the number of observations and the range of d. The histogram chart has d values as the X-axis and the number of districts as the Y-axis.

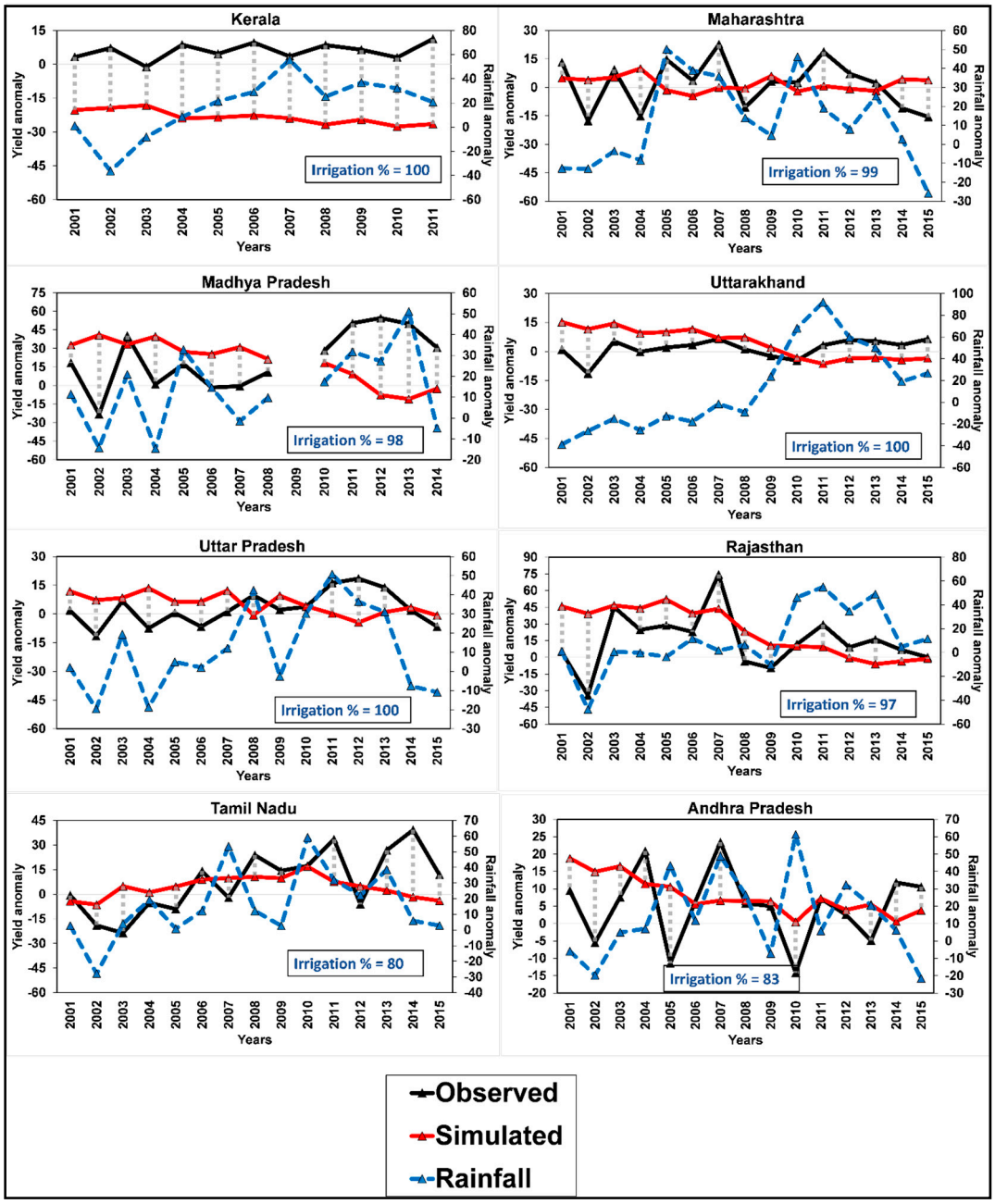

Figure S5: Time series of observed and simulated yield anomalies and rainfall anomalies. Curves are observed yield anomalies (Observed, green), simulated yield anomalies (Simulated, magenta), and rainfall anomalies (Rainfall, blue). The left y-axis represents the observed and simulated yield anomalies; the right y-axis represents the rainfall anomaly. Years are on the x-axis. The red dotted lines show the error between observed and simulated yield anomalies.

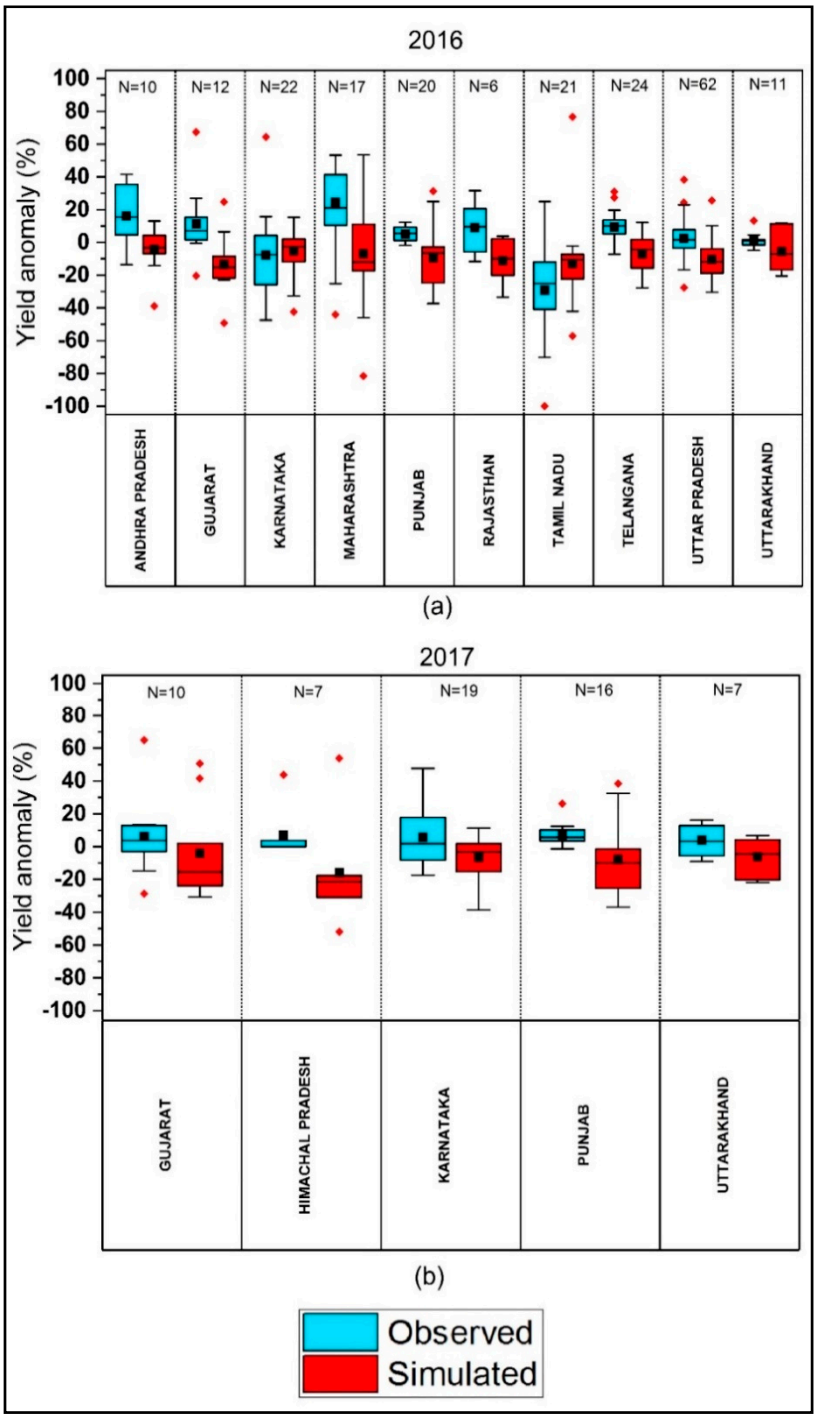

Figure S6: The grouped boxplots of observed and simulated yield anomalies for the years 2016 and 2017. The blue boxplots represent the observed yield anomalies; The red boxplots represent the simulated yield anomalies; The number of observations was given above the boxplot; The line in the boxplots are median; squared black dots are mean and red diamond dots are the outliers. Plot a consists of states from Southern India, plot b consists of states from Central India, and Northern India and plot c consists of states from Northern India and Himalayan regions.

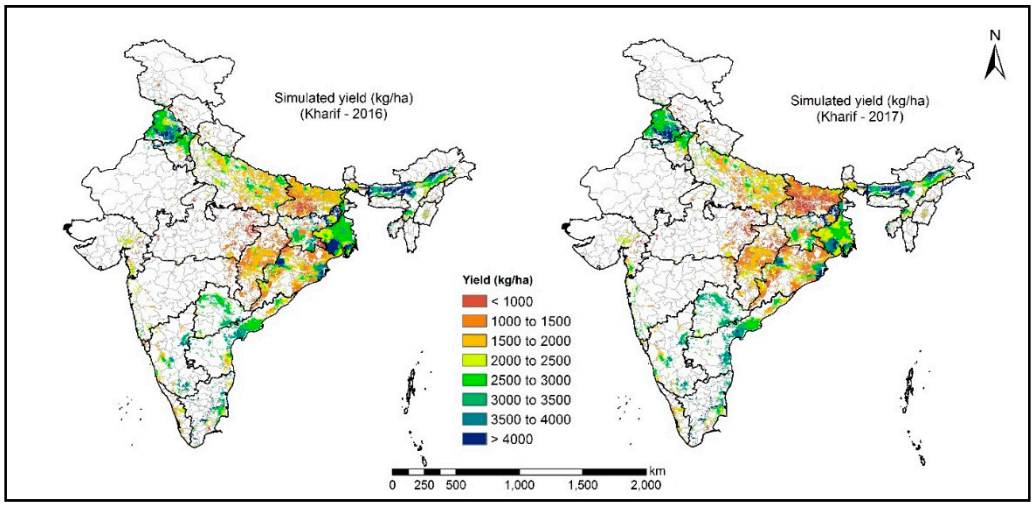

Figure S7: The high-resolution spatial distribution map of actual yield for Kharif 2016 (left-hand side) and Kharif 2017 (right-hand side).

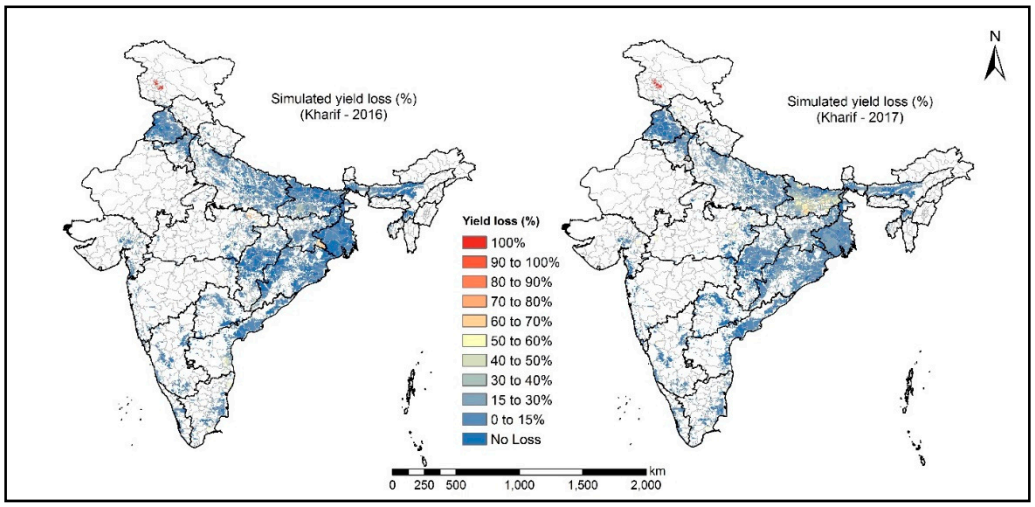

Figure S8: The high-resolution spatial distribution map of yield loss for Kharif 2016 (left-hand side) and Kharif 2017 (right-hand side).

Figure S8 shows that there is not much yield loss in Kharif 2016 rice yield except few parts in Madhya Pradesh. In Kharif 2017, there was not much yield loss except Bihar.