OPEN BURNING OF AGRICULTURAL RESIDUES

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Emission inventory of different pollutants from the burning of different crop residues in the cropland is being developed following the IPCC (2006) inventory preparation guideline. The primary crops considered for inventory preparation are rice, wheat, maize, sugarcane, and cotton, as mentioned in different published literature. Emission from the in-situ burning of crop residue was calculated using Eq. 23:

$$Epol = \sum_{S=1}^{35} \sum_{D=1}^{n} \sum_{C=1}^{n} Pa \times Ra \times fDa \times fBa \times EFpol \quad (23)$$

where, Epol = Emission of a particular pollutant (pol) (g); Pa is the total production of a particular crop (C) in a particular district (D) of the state (S) in kilograms; Ra is the fraction of residue generated for the production (Pa) of the particular crop (a); *f*Da is the fraction of dry matter in the residue of the particular crop (a); *f*Ba is the combustion efficiency of crop residue that is burnt; and *EFpol* is the emission factor of the particular pollutant (g/kg). During the course of the present study, crop residue samples were collected from different parts of the country to develop the *EFpol* of different pollutants emission while burning the crop residues (*Annexure I*). VIIRS dataset of the Fire information for Resource Management System (FIRMS) of NASA was used to identify the crop residue burning locations all over the country while collecting the crop residue samples. The VIIRS sensor is placed aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite. The 375-m active fire product of VIIRS was used for this study. The 375-m data complements Moderate Resolution Imaging Spectroradiometer (MODIS) fire detection; they both show good agreement in hotspot detection but the improved spatial resolution of the 375-m data provides a greater response over fires of relatively small areas and provides improved mapping of large fire perimeters using pixel-integrated Fire Radiative Power (FRP). The VIIRS 375-m FRP dataset of the year 2016 was overlaid on the seasonal cropland map of India to extract the crop residue burning activities during the harvest seasons of Kharif (wet) and Rabi (dry) seasons crops.

The seasonal (wet season and dry season) production data (Pa) of different crops were collected from the Department of Agriculture Cooperation and Farmers' Welfare (DAC&FW), Ministry of Agriculture, Government of India for the year 2016. Crops were categorized into the following six groups in the present study, a) rice, b) wheat, c) cotton, d) maize, e) sugarcane and f) others based on the field observation of crop residue burning. The 'others' group includes, tur, mustard, cassava, tiger grass, and jute. The state-level production of different crops is given in Table 23.

Table 23 State-level production (Mg) of different crops during dry and wet seasons of 2016

State	Rice	Wheat	Cotton	Maize	Sugarcane	Others
Andaman & Nicobar Islands	0	0	0	352	2338	1
Andhra Pradesh	557,500	52,547	413,780	256,422	129,225	258,379
Arunachal Pradesh	264,433	144,521	0	201,452	197,795	0
Assam	0	129,083	144,707	186,996	121,575	517
Bihar	0	4,736,448	0	2,288,789	11,914,615	0
Chandigarh	206	5060	0	80	0	0
Chhattisgarh	5,154,328	142,329	94	237,676	46,895	0
Dadra & Nagar Haveli	29,598	302	0	99	51,300	220
Daman & Diu	3600	0	0	0	0	0
Goa	115,068	28,800	700	65,200	11,022,477	0
Gujarat	1,584,355	2,315,849	7,542,431	608,511	10,947,109	563
Haryana	3,941,000	11,117,000	1,783,500	26,000	7,500,000	13,863
Himachal Pradesh	114,648	602,102	0	707,890	37,516	0
Jammu & Kashmir	646,362	544,889	1	523,609	290	0
Jharkhand	222,218	113,828	0	115,255	9140	31,910
Karnataka	2,713,089	128,988	1,152,047	3,310,473	0	148,704
Kerala	0	0	196	74	13,813	1845
Lakshadweep	0	0	0	0	0	0
Madhya Pradesh	3,246,000	15,705,000	738,000	2283,000	3,980,000	0
Maharashtra	2,517,100	952,551	3,913,230	1,594,670	58,271,000	128,700
Manipur	0	0	0	0	0	0
Meghalaya	62,901	875	8928	41,242	356	0
Mizoram	37,746	0	77	10,295	51,270	0
Nagaland	439,460	5950	80	136,360	190,200	0
NCT of Delhi	0	0	0	0	0	0
Odisha	5,874,000	0	0	110,977	577,157	0
Puducherry	31,070	0	271	0	213,968	0
Punjab	11,823,022	16,077,185	39,3000	42,4637	6,607,000	0
Rajasthan	369,780	10,468,161	206,448	1,156,675	531,267	0
Sikkim	19,687	346	0	68,310	0	0

State	Rice	Wheat	Cotton	Maize	Sugarcane	Others
Tamil Nadu	7,374,681	0	326,659	2,532,330	25,508,824	0
Telangana	3,047,289	16,902	3,733,072	1,751,074	2,404,655	937
Tripura	575,826	407	1365	12,177	40,492	0
Uttar Pradesh	12,434,053	26,874,361	2658	1,303,866	145,384,798	20,143
Uttarakhand	591,755	790,370	0	38,208	5,656,014	0
West Bengal	15,948,254	788,503	1326	662,434	1,327,805	4960
Total	79,739,030	91,742,357	20,362,570	20,655,132	292,738,893	610,742

DAC&FW, Ministry of Agriculture, Government of India

The residue to crop fractions (Ra) of different crops was replicated as in Datta and Sharma (2016). The dry matter fraction in different crop residues () were replicates as reported by Jain et al. (2014). The combustion efficiency (*f*Ba) of different crop residues were used as reported in Turn et al. (1997). Table 24 summarizes different coefficients used to estimate the emissions of pollutants from burning of crop residues using *eq. 23*.

Table 24 Coefficients of different crop residues to estimate the emissions of different pollutants

Co-efficient	Rice	Wheat	Cotton	Maize	Sugarcane	Others
Residue to crop ratio (Ra)[1]	1.59	1.70	0.40	3.00	2.00	2.00
Dry fraction of residue (*f*Da)[2]	0.86	0.88	0.80	0.90	0.80	0.90
Combustion efficiency (*f*Ba)[3]	0.89	0.86	0.90	0.92	0.68	0.91

[1]Datta and Sharma (2016); [2]Jain et al. (2014), [3]Turn et al. (1997)

The VIIRS dataset of the FIRMS was also used to identify the crop residue burning locations at 36 km × 36 km grid over the country boundary during the dry (April–May) and wet (October–December) crop harvesting seasons of 2016 (Figure 10). All districts were divided into different polygons based on the 36 km × 36 km grids. Total number of fire event in each polygon was calculated. Each polygon was allotted a weighted value based on the number of fire events. The weighted values of each polygon were; 0.1 if number of burning events were >0 and <10, 0.3 if number of burning events were >10<=50; 0.6 if number of burning events were >50<=100; 0.8 if number of burning events were >100<=1000, and 1 if number of burning events were >1000.

Each polygon area was divided with the harvested area of each crop in a district (DAC&FW, Ministry of Agriculture, Government of India, 2016) to calculate a factor to allot the amount of crop residue available in a polygon using Eq. 24:

$$[B_{Poly}]_C = \frac{APoly}{Ac} \times [Pa]_C \times [Ra]_C \times [fDa]_C \times [fBa]_C \qquad (24)$$

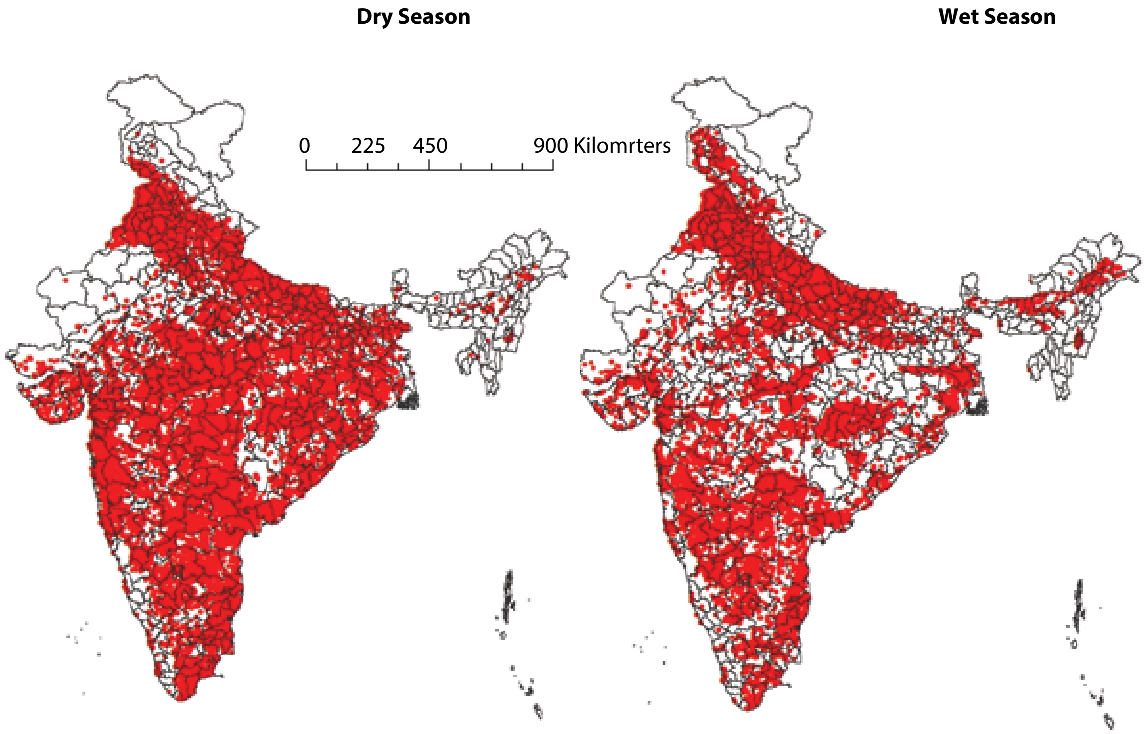


Figure 10 Locations of crop residue burning at the agriculture field during the harvest period of dry and wet season crops during 2016. Data source: MODIS-VIIRS

where, $[B_{Poly}]_C$ is the burnable fraction (Mg) of crop type C in a polygon; A*Poly* is the area of the polygon (ha); A_C is the total harvested area (ha) of crop C in the district; $[Pa]_C$, $[Ra]_C$, $[fDa]_C$ and $[fBa]_C$ are the district-level production (Mg), residue to crop ratio, dry fraction of residue and combustion efficiency of the crop C. $[B_{Poly}]_C$ was multiplied with the respective number of fire weighted values of respective polygon to estimate the amount of each crop residues burnt (Mg) in each polygon during a crop harvest season. Accordingly, it was estimated that about 17% of total crop residues generated during 2016 were burnt in the field (Table 25).

Table 25 Estimated amount of different crop residues and burnt amount during 2016

Crop type	Residue generated (Mg)	Residue burnt (Mg)
Rice	126,785,058	30,637,767
Wheat	155,962,007	11,134,512
Cotton	61,087,709	8,127,676
Maize	41,310,265	5,019,477
Sugarcane	117,095,557	32,018,180
Others	1,221,483	141,327
Total	503,462,079	87,078,939

The emission factors of different pollutants (Table 26) as measured using the method described in *Annexure I* was used to calculate the emissions of different pollutants in each polygon using Eq. 25:

$$Epol = [B_{Poly}]_C \times W_i \times EF_{Pol} \quad (25)$$

where, E_{pol} is the emission of a particular pollutant (pol) in kg; W_i is the weighted value of number of fire; and EF_{Pol} is the emission factor of a pollutant (pol) in kg/Mg.

Table 26 Emission factors (kg/Mg) of different pollutants during the burning of crop residues

Crop	PM_{10}	$PM_{2.5}$	SO_x	NO_x	CO	NMVOC	NH_3
Rice	14.60	9.26	2.12	5.70	79.61	6.49	1.30
Wheat	11.33	8.51	1.14	5.98	97.96	7.43	1.30
Cotton	11.78	9.78	0.37	6.41	123.22	6.86	1.30
Maize	13.64	11.18	0.38	6.82	47.81	9.87	1.30
Sugarcane	18.28	11.98	0.52	6.05	62.93	5.91	1.30
Others	24.96	15.05	0.79	8.90	130.27	8.24	1.30

* NH_3 emission factor was taken from GAINS-ASIA.

8.1 Emission inventory of different pollutants during the open burning of crop residue

Seasonal emissions of different pollutants from the burning of different crop residues were estimated using Eq. 23.

Figure 11 shows the seasonal emissions of different pollutants from the burning of different types of crop residues.

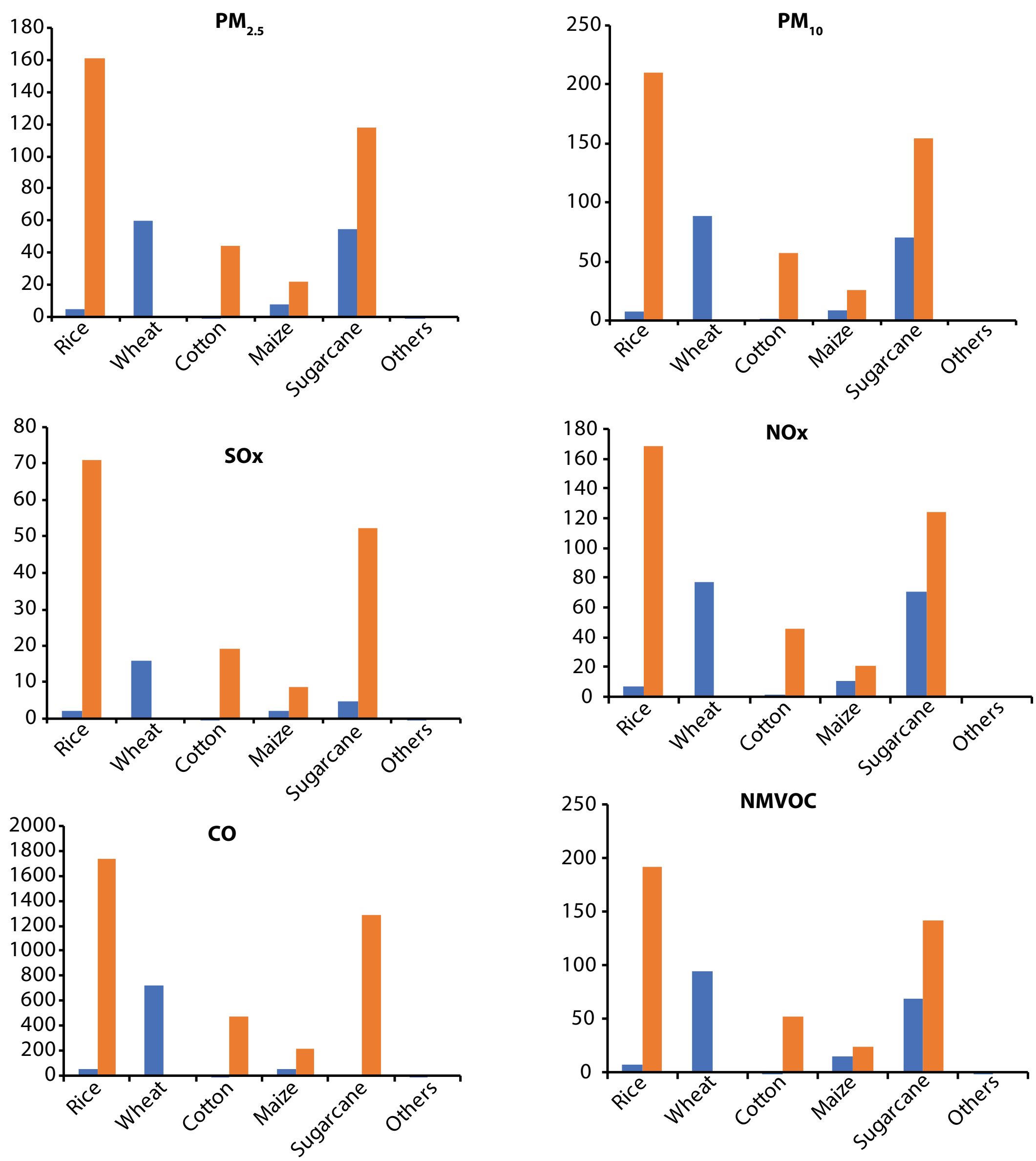
Table 27 summarizes the emission of different pollutants from the burning of different types of crop residues in respect of the crop production.

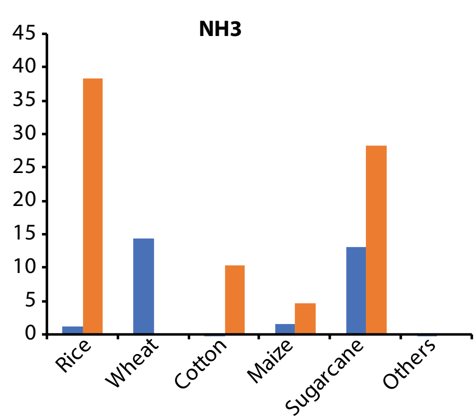
Table 27 Estimated emissions (Gg) of pollutants per unit production (Tg) in different seasons

Crop	PM_{10}		$PM_{2.5}$		SO_x		NO_x		CO		VOC		NH_3	
	D	W	D	W	D	W	D	W	D	W	D	W	D	W
Rice	0.22	5.91	0.14	3.75	0.03	0.86	0.09	2.31	1.20	32.24	0.10	2.63	0.02	0.53
Wheat	1.59	-	1.19	-	0.16	-	0.84	-	13.70	-	1.04	-	0.18	-
Cotton	0.00	5.84	0.00	3.91	0.00	0.85	0.00	2.28	0.05	31.87	0.00	2.60	0.00	0.52
Maize	1.07	3.47	0.87	2.66	0.03	0.50	0.53	1.35	3.73	18.92	0.77	1.54	0.10	0.31
Sugarcane	10.33	2.15	6.77	1.77	0.29	0.31	3.42	0.84	0.57	11.75	3.34	0.96	0.73	0.19
Others	1.36	3.55	0.82	3.66	0.04	0.52	0.49	1.39	7.11	19.38	0.45	1.58	0.07	0.32

D: Dry season; W: Wet season

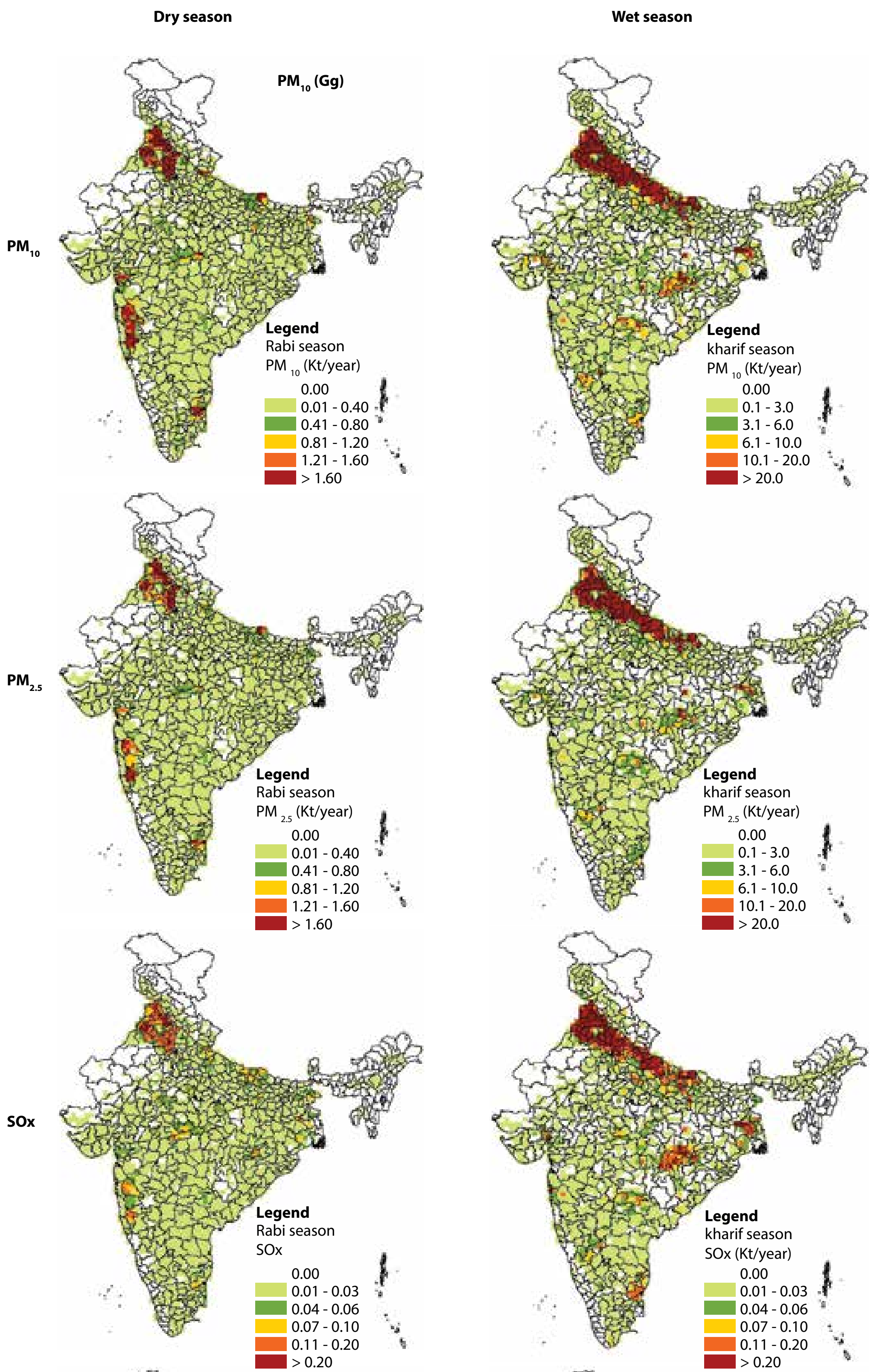
Seasonal emissions of different pollutants due to the open burning of the crop residues in the agricultural fields were distributed to 36 km × 36 km grids (Figure 12) following Eq. 24.





A. Rice; B. Wheat; C. Cotton; D. Maize; E. Sugarcane; and F. Others

Figure 11 Estimated seasonal emission of pollutants from the crop residue burning in 2016



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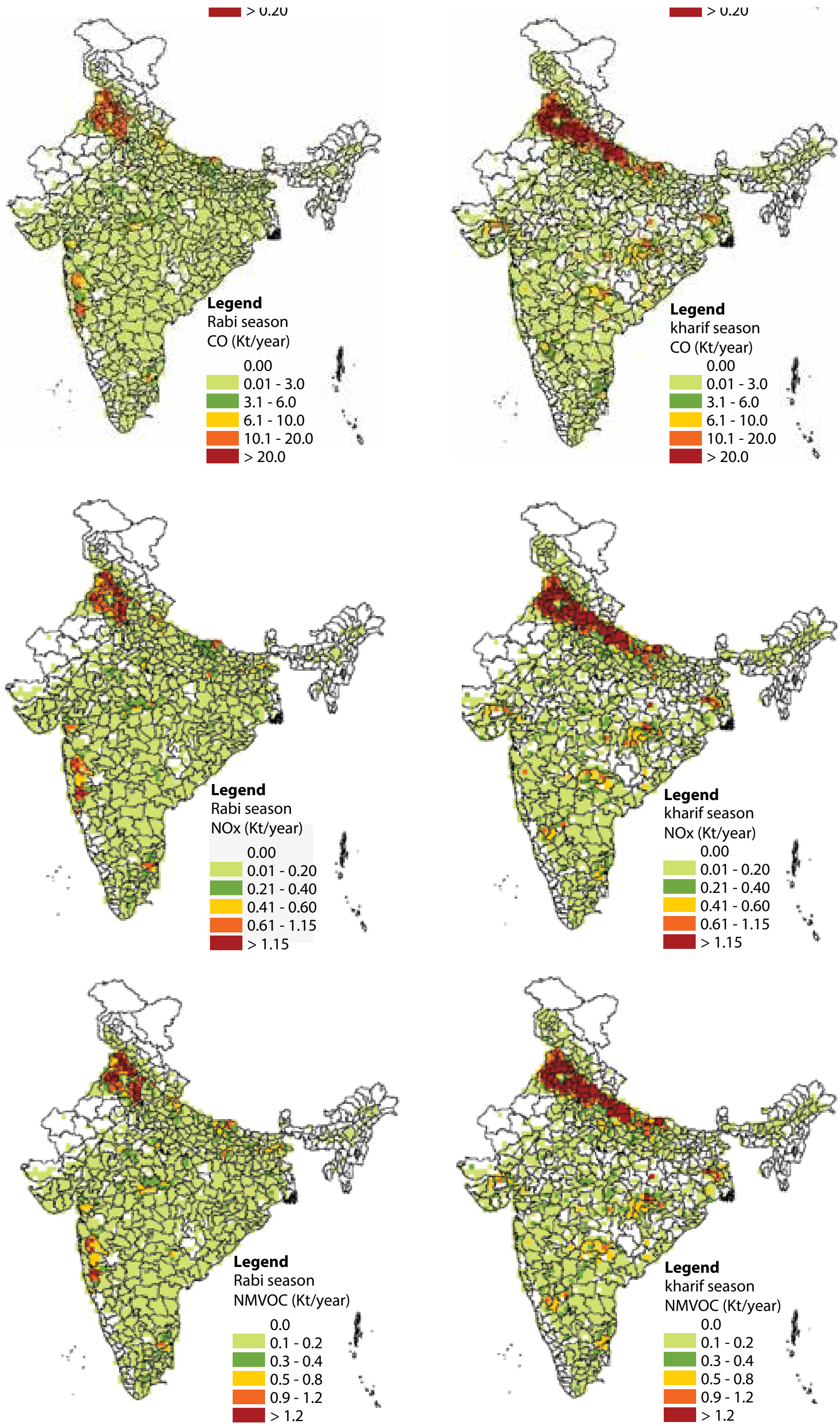

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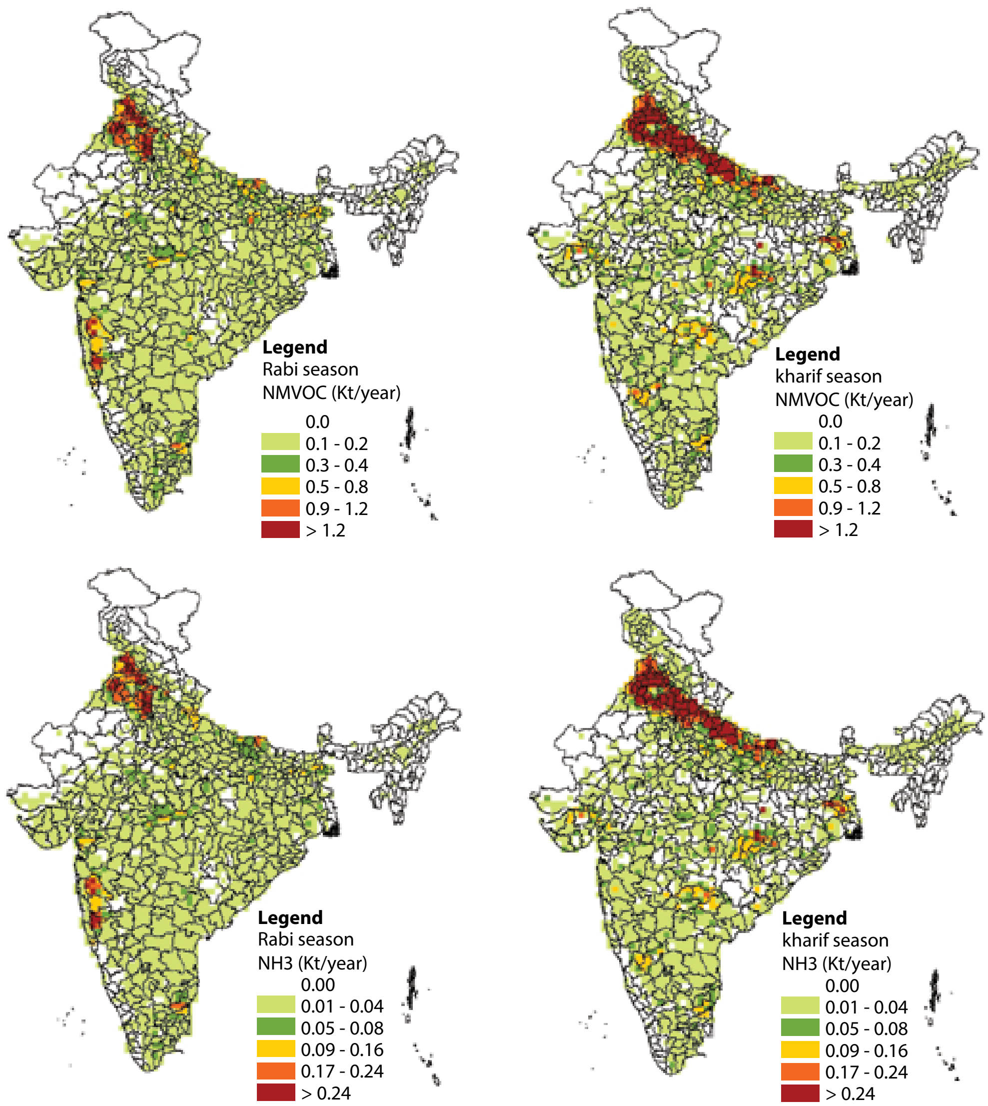

Figure 12 Spatial variation of emissions of different pollutants due to burning of crop residues in agricultural field during different crop harvesting periods

Annual emissions of PM_{10}, $PM_{2.5}$, SO_x, NO_x, CO, NMVOC and NH_3 due to burning of crop residues are 1325, 937, 158, 527, 6501, 600, and 118 Gg, respectively (Table 5). Annual emission of PM_{10} and $PM_{2.5}$ was higher from the burning of sugarcane residues (934 Gg) all over the country compared to other crop residues burnt in the field during 2016. While, SO_x, CO and NMVOC emissions were recorded higher from the burning of rice crop residues in the entire country compared to other crop residues (Table 28).

Table 28 Annual emissions (Gg) of different pollutants from the burning of crop residues in the croplands during 2016

Crop	PM_{10}	$PM_{2.5}$	SO_x	NO_x	CO	VOC	NH_3
Rice	450	285	65	176	2453	200	40
Wheat	145	109	15	77	1257	95	17
Cotton	119	80	17	47	655	53	11
Maize	76	59	8	32	370	40	7
Sugarcane	533	402	52	195	1752	211	44
Others	3	2	0	1	14	1	0
Total	1325	937	158	527	6501	600	118