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RESEARCH ARTICLE

Ambient air quality changes after stubble burning in rice–wheat system in an agricultural state of India

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Abstract

Ground-based ambient air monitoring was conducted to assess the contribution of crop residue burning of wheat (*Triticum aestivum*) and rice (*Oriza sativa*) at different locations in three districts (Kaithal, Kurukshetra, and Karnal) of the agricultural state of Haryana in India for two successive years (2016 and 2017). The Air Quality Index (AQI) and concentration of primary pollutants (SO_x, NO_x, and $PM_{2.5}$) were determined in rice and wheat crop season, for burning and non-burning periods. During crop residue burning periods, concentrations of SO_x, NO_x, and $PM_{2.5}$ were exceeded the NAAQS values by 78%, 71%, and 53%, respectively. A significant increase in SO_x (4.5 times), NO_x (3.8 times), and $PM_{2.5}$ concentration (3.5 times) was observed in stubble burning periods as compared to pre-burning ($p < 0.05$). A positive and significant correlation among the three pollutant concentrations was observed ($p < 0.01$). The AQI of KA site in Karnal district fell in severely polluted category during 2016 for rice as well as wheat residue burning period, and of KK site in Kaithal during wheat residue burning in year 2017. Results of present study indicate a remarkable increase in pollutant concentration (SO_x, NO_x, and $PM_{2.5}$) during the crop residue burning periods. To the best of our knowledge, the outcomes of present study in this region have not been reported in earlier reports. Hence, there is an urgent need to curb air pollution by adopting sustainable harvesting technologies and management of residues.

Keywords Stubble burning · Rice–wheat system · Air Quality Index · SO_x · NO_x · $PM_{2.5}$

Abbrevations

$PM_{2.5}$	Particulate matter
SO_x	Oxides of sulfur
NO_x	Oxides of nitrogen
AQI	Air Quality Index
RWS	Rice–wheat system
$\mu g/m^3$	Microgram/meter cube
NAAQS	National Ambient Air Quality Standards
th. ha	Thousand hectare

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Introduction

Mechanized harvesting technologies leave behind large quantities of residue in the field for open burning. Biomass burning during wheat and rice harvesting periods emits the large amount of trace gases and particulates which reach a long distance through prevailing winds and deplete the air quality at local as well as regional levels (Venkataraman et al. 2006). The burning of crop residue is an important source of air pollutants, such as particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), black carbon (BC), and volatile organic compounds (VOCs), which may have remarkable negative effects on climate (Zhang et al. 2008), regional air quality (Kharol and Badarinath 2006; Cheng et al. 2014; He et al. 2015; Huang et al., 2012) and human health (Gadde et al. 2009; Zhang et al. 2016). An increase in black carbon, particulate pollution, greenhouse gases, and other polluting gases from crop residue burning has made the Indo-Gangetic basin a global hotspot of atmospheric pollutants and a place for recurring winter haze and toxic fog. Higher concentration of oxides of sulfur causes acid rain and sulfurous smog, and reduced atmosphere visibility.

Particulate matter causes respiratory problems such as asthma, reduction in visibility, and cancer. It also affects lungs and tissues (Khandbahale and Saler 2013). Oxides of nitrogen cause respiratory problem, asthma, lung irritation, and pneumonia. Combination of particulate matter with sulfur oxides is more harmful than either of them separately (Balashanmugam et al. 2012). Strong relationships have been observed between the higher concentration of SO_x and NO_x and several health effects such as cardiovascular diseases (Curtis et al. 2006), and respiratory health effects such as asthma and bronchitis (Zanobetti and Schwartz 2002; Peters et al. 2004; Chen et al. 2005; Dockery et al. 1993; Ye et al. 2001; Barnett et al. 2005). Other acute effects of pollutants are stuffy or runny nose, sinusitis, sore throat, wet cough, head cold, hay fever, burning or red eyes, and many more (Dockery et al. 1993), affecting one's working capacity. Residue burning at times also causes poor visibility and increases the incidences of road accidents (Grover et al. 2015).

The two states of Punjab and Haryana alone contribute 48% of the 13915 Gg (Giga gram = 10 billion gram) rice straw surplus produced in India and are subject to open field burning (Gadde et al. 2009). Rice–wheat (R–W) system in Haryana is mostly concentrated in the northeastern and northwestern part of Yamuna and Ghaggar flood plains occupying 9.16 lac hectares, which is 24.75% of the total agricultural area of the state (Panigrahy et al. 2008). Planting of rice in Haryana takes place in June and July and paddy is harvested from the first fortnight of October to the first fortnight of November and wheat is sown immediately after rice harvesting during the months of November–December. After harvest, the residue is frequently burned in open fields because burning is the easiest and economical option for the farmers and there is insufficient time to dispose it off in a more controlled manner before the next crop is planted. Due to lack of awareness or non-availability of suitable technologies to the farmers, it is generally practiced everywhere and it leads to emission of particulate matter (PM_{10} or $PM_{2.5}$) and gaseous pollutants (CO_2, CH_4, CO, N_2O, NO_x, and SO_2) into ambient air. Crop residues are a good source of plant nutrients and are important components for the stability of the agricultural ecosystem (Singh and Sidhu 2014; Yadav et al. 2017; Kaur et al. 2018). About 25% of N and P, 50% of S, and 75% of K uptake by cereal crops are retained in crop residues, making them viable nutrient sources (Singh et al. 2003; Lohan et al. 2017). Stubble flaming also burns the nutrients present in residues with huge pollution as an outcome. Burning of crop residue has been reported to emit gases such as SO_2, NO_2 and CO_2, and N_2O and CH_4 (Tripathi et al. 2013; Jain et al. 2014). During residue burning, all the emissions are fugitive and smoke escapes through unplanned exits in the downwind direction. Burning of agricultural waste in many Asian countries may substantially contribute to the formation of atmospheric brown cloud that affects the local air quality, atmospheric visibility, and the earth climate (Mishra et al. 2014).

Despite the increasing evidence of negative impact of the deteriorating air quality through residue burning (Singh et al. 2010; Jain et al. 2014, Tripathi et al. 2015), data on ambient air quality affected by residue burning is still limited in respect of Haryana. Furthermore, this is a pioneer study for assessing the impacts of residue burning over ambient air quality for selected districts of Haryana, where this problem is aggravated and is being attributed to contribute to smog in the neighboring National Capital Region (NCR) of India. Hence, the present study was designed to assess the concentration of $PM_{2.5}$, SO_x, and NO_x in ambient air and also to determine AQI during periods of crop residue burning for rice and wheat crops at different study sites. Data obtained from the present study will help in formulating the strategies for maintaining the ambient air quality and its associated human health.

Methodology

Study area

Three districts in Haryana, namely, Kaithal, Karnal, and Kurukshetra, situated between 29° 27′ to 30° 15′ N latitudes and 76° 08′ to 77° 15′ E longitudes, were selected for the study (Fig. 1) as they are the major wheat/rice stubble burning districts in the state. The geographical area of Kaithal, Karnal, and Kurukshetra districts is 2317 sq. km, 2520 sq. km, and ,530 sq. km, respectively. Out of each district, a model village was selected on the basis of continuous rice–wheat rotation system being followed without any intermediate crop and the residue burning being continuously practiced since past 5 years within that village. The districts have a subtropical continental monsoon climate with hot summer and cool winter. The average annual rainfall of three districts Kaithal, Karnal, and Kurukshetra for the 5 years (2012–2016) was 303.7, 544.5, and 354.7 mm, respectively (State Statistical Abstract of Haryana 2017). About 80% of the annual rainfall is generally received during June to September months. In this region, temperature starts rising from March and continue till the end of June. May and June are the hottest months with mean daily maximum temperature at about 40 °C. Temperature sometimes may rise up to 45 °C. During winter, the temperature starts decreasing by the middle of November; January is the coldest month. These districts are part of the Indus-Ganges plain (Upper Yamuna Basin) and soil type is sandy loam alluvial soil. In R–W system, rice is grown in the warm, sub-humid monsoon, summer months and wheat in the cooler, drier, winter season. Both crops are grown in one calendar year.

***Kurukshetra (Mirzapur village) (KM)*:** Mirzapur village is situated in the Thanesar block of Kurukshetra district of the Haryana State. Kurukshetra lies between latitude 29° 53′ to 30° 15′ N and longitude 76° 26′ to 77° 04′ E in the northeastern part of Haryana State. The village is situated on National Highway-1 (NH1)

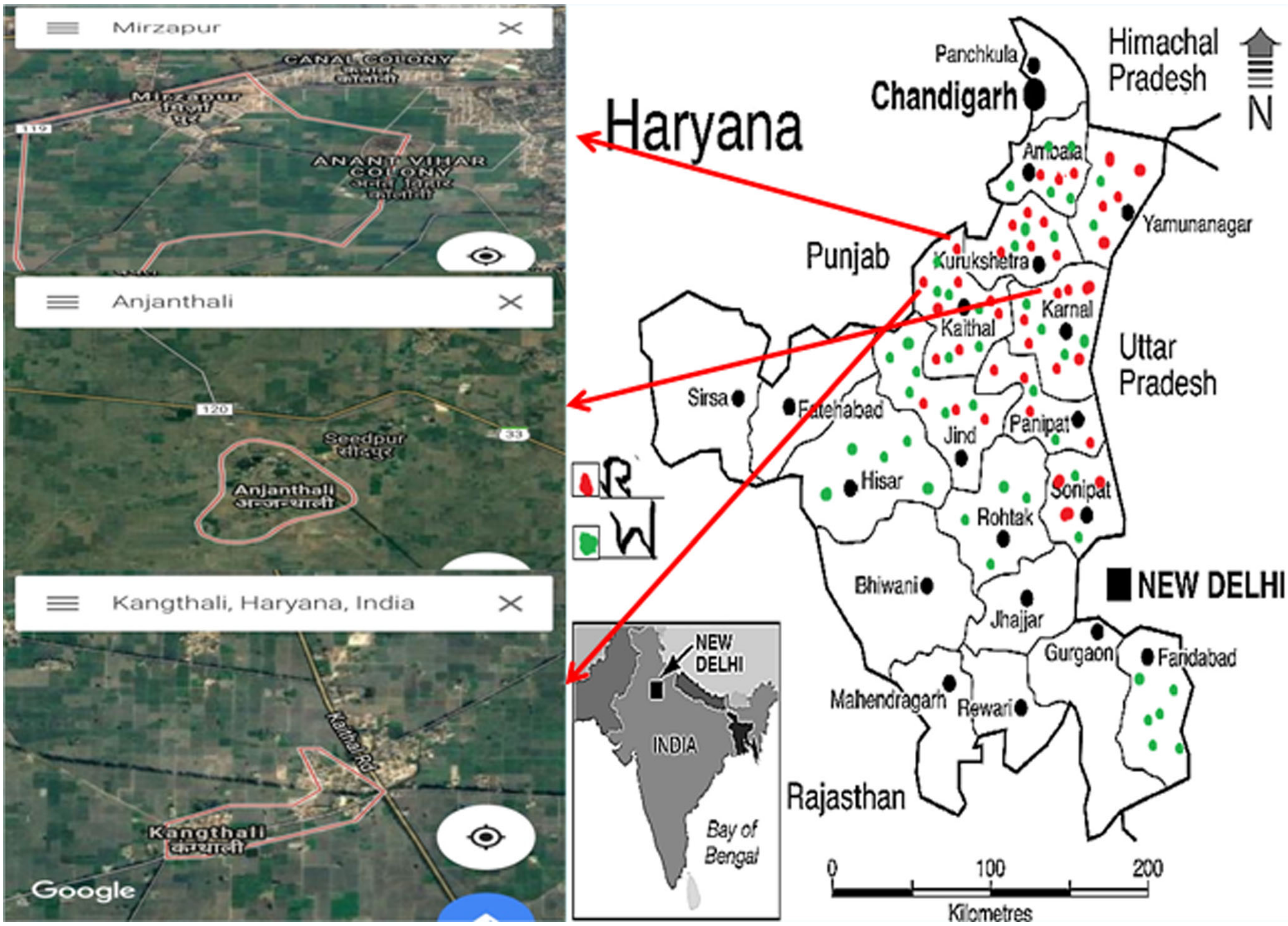

Fig. 1 Location of different study sites selected for the ambient air sampling

about 4.4 km far from the main city of Kurukshetra covering an area of 1530 sq. km. and having population size 5490.

Karnal (Anjanthali village) (KA): Anjanthali is 5 km from the town Nilokheri and 25 km away from Karnal. It lies on the geographical coordinates of 29° 41′ 0″ N, 76° 59′ 0″ E. The total geographical area of village is 627 ha. Anjanthali has a total population of 3459 peoples. There are about 671 houses in Anjanthali village.

Kaithal (Kangthali village) (KK): Kangthali is a large village located in Guhla block of Kaithal district, Haryana. It lies on the geographical coordinates of 30.0379 N, 76.7853 E. latitude and longitude of the Kaithal city with total 536 families residing in the village. This village has population of 2910 as per Population Census 2011.

Sampling and analytical procedure

For sampling, three different locations were selected carefully at each study site, taking natural wind direction and land use patterns into consideration. The site selected had a broad open area with no major built up area and also the accessibility and security of sampling instruments and electricity supply during air sampling were taken into consideration. The air samples were collected using air samplers installed on the roof of a single stored building or structure near agricultural fields (about 11 feet height) (CPCB, 2012-13). From each study site, 6 samples each for pre-burning period and burning period were collected for ambient air quality analysis. Hence, total 36 samples were collected for one crop. The impact of residue burning of two crops, i.e., summer harvested wheat and winter harvested rice, was studied for 2 years (2016 and 2017). The total time period of monitoring was categorized as pre-burning period, i.e., just after the harvesting (Sept–Oct, 2016, 17 for rice and Mar–Apr, 2016, 17 for wheat), and burning period (Oct–Nov, for rice and Apr–May, 2016, 17 for wheat).

Time averaged in situ sampling for 24 h with flow rate 1 m^3 was done to measure the concentration of particulate matters ($PM_{2.5}$) and gaseous pollutants (NO_x, SO_x) at each sampling site. The concentration of $PM_{2.5}$ was measured with a high volume sampler (Envirotech APM 550). In this sampler, air is drawn through an omni-directional inlet designed to provide a clean aerodynamic cut point at 2.5 microns. The air sample and fine particulates are passed through a 47 mm diameter Teflon filter membrane that retains the particulate matter on $PM_{2.5}$ impactor. The flow rate was maintained at 1 m^3/h by a suitable critical orifice. The dry gas meter provides a direct measure of the total air volume sampled. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of suspended particulate matter in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

Oxides of sulfur (SO_x) were also measured by the high volume sampler (Envirotech APM 550). Ambient air was continuously drawn into 25 ml of potassium tetrachloromercurate (TCM) solution at a flow rate of 1 lpm and analyzed with spectrophotometer (Systronic 117 UV- Visible Spectrophotometer) in laboratory by modified method of West and Gaeke (1956).

Oxides of nitrogen (NO_x) were measured using the same high volume sampler (Envirotech APM 460BL). Ambient air was continuously drawn into 25 ml of sodium hydroxide solution. The average flow rate of ambient air was 1 lpm and analyzed with spectrophotometer (Systronic 117 UV–Visible Spectrophotometer) in laboratory by modified method of Jacobs and Hochcheiser (1958).

Air Quality Index

AQI was calculated using the method suggested by Tiwari and Ali (1987). The air quality rating of each pollutant was calculated by the following formula:

$$Q = 100 \times V/Vs$$

where Q represents quality rating, V the observed value of the pollutant, and Vs the standard value recommended for that pollutant. The Vs values used are the recommended National Ambient Air Quality Standards (Table 1) for different areas.

If total "n" number of pollutants were considered for air quality monitoring, geometric mean of these "n" number of quality rating was calculated as:

$$g = antilog(loga + logb + logc + \ldots logx)/n$$

Table 1 National ambient air quality standards for 24 h time-weighted average

Pollutants	Concentration in residential/agricultural fields (μg/m^3)
SO_x	80
NO_x	80
$PM_{2.5}$	60

Source: NAAQS (2009), Central Pollution Control Board (CPCB), New Delhi, India

where "g" is geometric mean, while "a, b, c, and x" represent different values of quality rating, and "n" is the number of values of quality rating.

Statistical analysis

The primary data set was processed and analyzed by using data analysis tool pack of MS Excel, 2007 for obtaining their average value, range, standard deviation, and standard error. All experimental data were expressed as means ± standard deviations of 6 replicates. To evaluate the relation between increasing concentrations of air pollutants over different years, crop, and regions, Pearson's correlation analysis was done using SPSS software package (IBM SPSS Statistics v 20) and expressed at $p < 0.05$ and $p < 0.01$.

Results and discussion

Kaithal, Karnal, and Kurukshetra being the major rice–wheat agricultural districts of Haryana, suffer from severe air pollution because of agricultural practice of the residue burning which has a detrimental impact on the ambient air quality. In order to quantify the impact of agricultural residue burning on the ambient air quality, the parameters SO_x, NO_x, and $PM_{2.5}$ were studied at three different locations of study site under each district during the rice and wheat harvesting period.

Variations in SO_x, NO_x, and $PM_{2.5}$ concentrations during pre-burning and burning periods

During non-burning period, the concentration of SO_x ranged from 11.07 to 26.35 μg/m^3, and during burning period it ranged from 29.57 to 156.77 μg/m^3 for rice in 2016 and 2017 season. For wheat residue burning, the values ranged from 40.95 to 189 μg/m^3. The NO_x concentration ranged from 11.25 to 39.25 μg/m^3 during non-burning period and from 59.86 to 176.1 μg/m^3 during the burning period of rice season. For wheat season, the value ranged from 58.4 to 139 μg/m^3 during burning period. The $PM_{2.5}$ concentration was in the range of 8.5 to 29.7 μg/m^3 during non-burning period but during burning period the concentration ranged from 39 to 98.77 μg/m^3 in rice season and from 32.1 to 118 μg/m^3 during burning period of wheat. A significant increase of 4.5-fold in SO_x, 3.8 in NO_x, and 3.5-fold in $PM_{2.5}$ concentration was observed ($p < 0.05$) in stubble burning period as compared to pre-burning. Burning of crop residue has been reported to emit gases such as SO_2, NO_2 and CO_2, and N_2O and CH_4 in various reports (Tripathi et al. 2015; Jain et al. 2014). The average data of AQI and SO_x, NO_x, and $PM_{2.5}$ concentrations with standard deviations at different monitoring sites is presented in Table 2.

Table 2 Average concentration of SO_x, NO_x, $PM_{2.5}$ (μg/m^3 ± SD) and AQI (Air Quality Index) category before and after burning at different monitoring sites in Haryana

Crop residue	Year	Sites	KM				KA				KK			
			SO_x	NO_x	$PM_{2.5}$	AQI category	SO_x	NO_x	$PM_{2.5}$	AQI category	SO_x	NO_x	$PM_{2.5}$	AQI category
Rice	2016	BB	13.73 ± 2.52	22.75 ± 1.56	14.2 ± 8.26	III	23.26 ± 2.35	28.59 ± 2.27	18.1 ± 1.9	III	15.14 ± 2.02	31.57 ± 5.0	15.03 ± 2.7	II
		AB	95.35 ± 12.59	100.95 ± 7.41	60.73 ± 12.53	VI	105.4 ± 45.23	137.34 ± 34.94	92.11 ± 24.27	VII	80.86 ± 26.15	93.14 ± 1.76	47.85 ± 1.51	IV
	2017	BB	19.82 ± 1.64	15.73 ± 2.67	12.76 ± 1.16	II	12.98 ± 2.03	14.05 ± 1.92	18.1 ± 3.87	III	21.65 ± 3.73	15.2 ± 1.47	13.00 ± 1.70	II
		AB	61.58 ± 26.5	72.47 ± 26.30	46.58 ± 18.21	V	29.57 ± 12.45	59.67 ± 21.39	45.21 ± 8.87	IV	55.38 ± 16.19	64.15 ± 5.67	25.43 ± 3.85	IV
Wheat	2016	BB	18.05 ± 2.59	28.32 ± 3.31	14.7 ± 2.45	III	26.35 ± 3.81	32.83 ± 4.25	18.78 ± 3.02	III	18.26 ± 1.20	21.73 ± 2.71	15.03 ± 1.49	II
		AB	62.1 ± 4.25	92.37 ± 3.51	60.73 ± 5.51	V	109.89 ± 18.79	133.25 ± 18.46	68.53 ± 23.29	VII	97.2 ± 5.6	102.53 ± 5.45	71.5 ± 4.10	VI
	2017	BB	22.24 ± 12.91	22.31 ± 4.49	14.33 ± 6.51	III	11.07 ± 4.18	25.93 ± 3.8	13 ± 1.71	III	18.13 ± 1.22	31.57 ± 5	15.86 ± 4.83	III
		AB	49.51 ± 8.04	59.907 ± 1.28	36.9 ± 4.38	IV	53.25 ± 5.52	103.37 ± 16.10	52.46 ± 6.13	V	143.98 ± 41.03	100.3 ± 37.46	89.43 ± 21.99	VII

Values are given as mean ± SD; n = number of replicates; n = 6 ; *BB* before burning; *AB* after burning

Source of SO_x and NO_x in the residue burning gases may be the sulfur and nitrogen present in residue which the plants uptake from the soil through organic matter, fertilizers, mineralization of parent material, atmospheric deposition, etc. Sulfur and nitrogen are taken up by plants as sulfate and nitrate, respectively, as anion that is mobile in the soil and subject to loss through leaching and volatilization. However, in case of sulfur, plant uptake is the major pathway for its removal from soil; therefore, sulfur deficiency in soil is increasingly being reported from many parts of Haryana, India. A fast decline in available sulfur in soil is chiefly due to higher crop removal by high yielding cultivars, crop intensification, poor replenishment of soil due to S-free fertilizers, i.e., urea, and DAP (Ram et al. 2014). However, in the regions of present study area, it is reported that 70% soils of these areas were high in available sulfur status with mean values of 25, 14, and 41 mg/kg in Kaithal, Kurukshetra, and Karnal districts, respectively. The higher status of available sulfur in these rice–wheat growing areas is due to sulfur-rich parent material and application of zinc sulfate as a common practice for correcting zinc deficiency in rice–wheat cropping system (Gyawali et al. 2016). Role of sulfur in Indian agriculture is now gaining importance because of the recognition of its role in increasing crop production of many cereals (Singh et al. 2000). The sulfur application is recommended for cereals at 20–40 kg/ha and an estimated 7745 tonnes of S is consumed through fertilizers annually in Haryana. Sulfur fertilization has also been reported to increase crude protein and grain yield as well as concentration in rice grain. Randall et al. (2003), also recorded a good response of rice to fertilization. An increase in grain yield of wheat due to fertilization has been reported by several researchers (Zhao et al. 1999; Jarvan et al. 2008; Ercoli et al. 2012).

However, in case of particulate matter, wheat and rice residue burning releases accumulation mode aerosols that mostly contribute to the $PM_{2.5}$ fraction (Hays et al. 2005). Because of their small size, these aerosols are more prone to long-range transport and have a longer life in the atmosphere. A substantial increase in $PM_{2.5}$ at all the study sites after-burning as compared to pre-burning leads to the conclusion that open burning of crop residues leads to great deterioration of air quality of study sites and adjoining areas. Similar findings have also been reported that concentration of particulate matter exceeds national and international standards during residue burning (Sidhu et al. 2015; Agarwal et al. 2012). During the crop residues burning periods, ambient $PM_{2.5}$ concentrations are subject to large episodic spikes due to anthropogenic sources (Guttikunda and Jawahar 2014; Gurjar et al. 2016). Moreover, satellite-based studies of post-monsoon burning in the Indo-Gangetic Basin (IGB) have shown elevated layers of aerosols (Mishra and Shibata 2012). During pre-burning period, gaseous pollutants (SO_x, NO_x) and aerosols ($PM_{2.5}$) were found below the NAAQS (i.e., 80 μg/m^3 for SO_x and NO_x; 60 μg/m^3 for $PM_{2.5}$). And in burning period, the maximum percent increase in

SO_x, NO_x, and $PM_{2.5}$ was 78.7%, 71.25%, and 53.5% respectively. Similar findings have been reported by Singh et al. (2010), and significant increase in SPM, SO_2, and NO_2 concentrations during rice crop residue burning periods (October and November) in 2006 and 2007 was observed as compared to non-burning periods in Patiala (Punjab, India).

Variations in SO_x, NO_x, and $PM_{2.5}$ ($\mu g/m^3$) levels at different sites of rice–wheat systems over 2 years

In order to identify the impact of crop residue burning on air quality, the concentrations of SO_x, NO_x, and $PM_{2.5}$ were plotted against the sampling periods, i.e., before burning and after burning for all the sampling sites during rice and wheat season. In present study, SO_x and NO_x concentrations were observed above the NAAQS at all the three sampling sites (KK, KA, and KM) in rice burning periods of 2016, whereas, in 2017, levels of SO_x and NO_x were observed to be below the standards (Fig. 2a, b). In wheat season of year 2016, SO_x concentration was above the standards at Kaithal (Kangthali village) (KK) site in Kaithal and Karnal (Anjanthali village) (KA) site in Karnal whereas, NO_x concentration was above the standards at all the three study sites (Fig. 2d, e). In year 2017, SO_x was below the standards at KA and Kurukshetra (Mirzapur village) (KM) sites but very high and much beyond standards at KK site (143.98 ± 41.03 $\mu g/m^3$) and also a corresponding increase was observed in NO_x and $PM_{2.5}$ during the period at site KK. This substantial increase in pollutants concentration can be attributed to uncontrolled burning of residues and also standing crop in large area due to accidental electric spark that happened in that area during wheat sampling period. There are many reports of uncontrolled fires and unintended loss of standing crops due to crop residue burning especially after wheat harvesting because of dry conditions and high temperature. Farmers also allege that during threshing, there are sparks from the threshing machine which triggers fire (Jitendra et al. 2017).

For rice residue burning, $PM_{2.5}$ concentration exceeded the standards in KM site at Kurukshetra and KA site in Karnal in

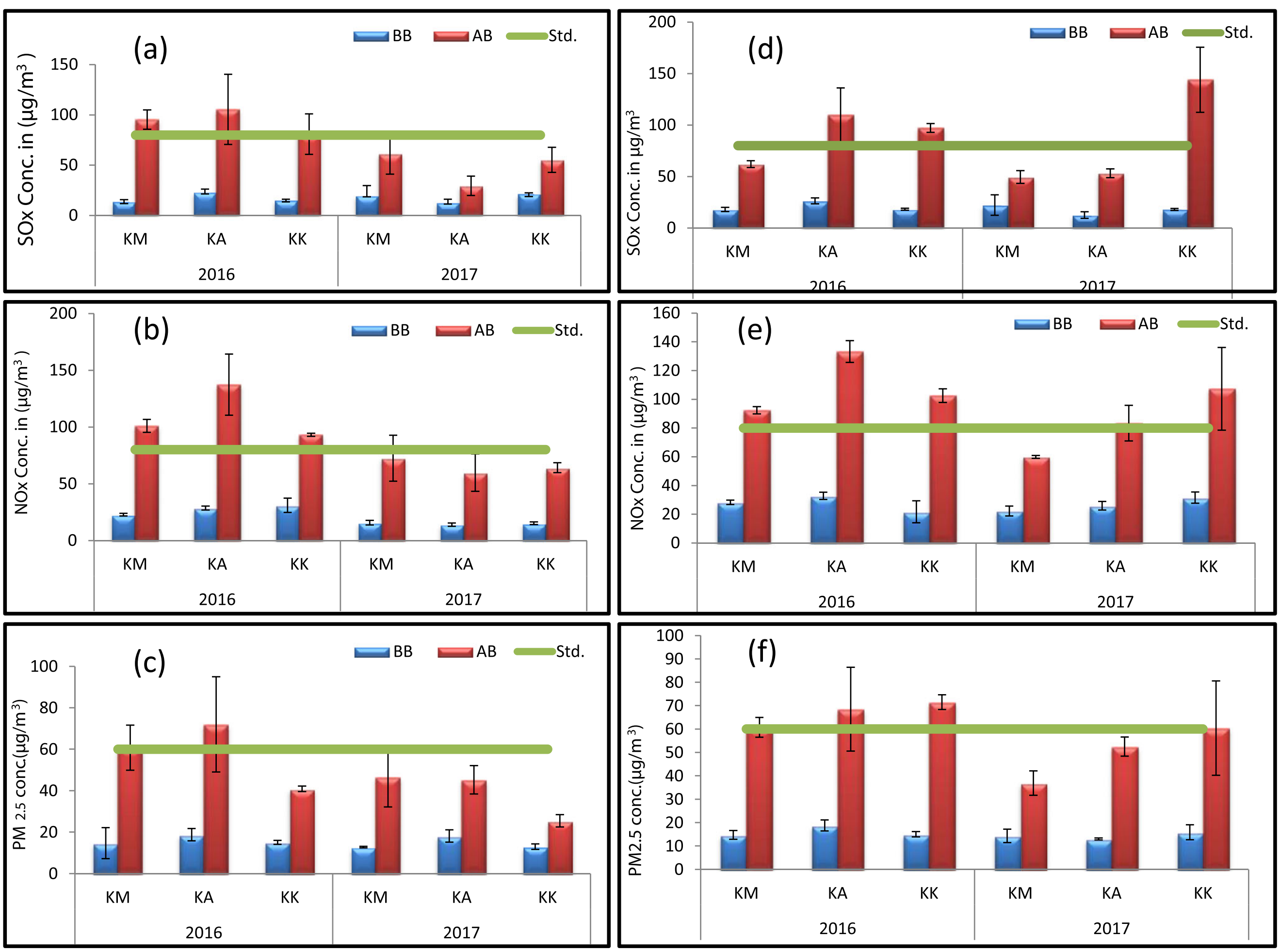

Fig. 2 Variations in air quality parameters and their comparison with NAAQ standards due to rice residue burning, **a** SO_x; **b** NO_x; **c** $PM_{2.5}$ and wheat residue burning **d** SO_x; **e** NO_x; **f** $PM_{2.5}$. (BB before burning; AB after burning; standard concentration)

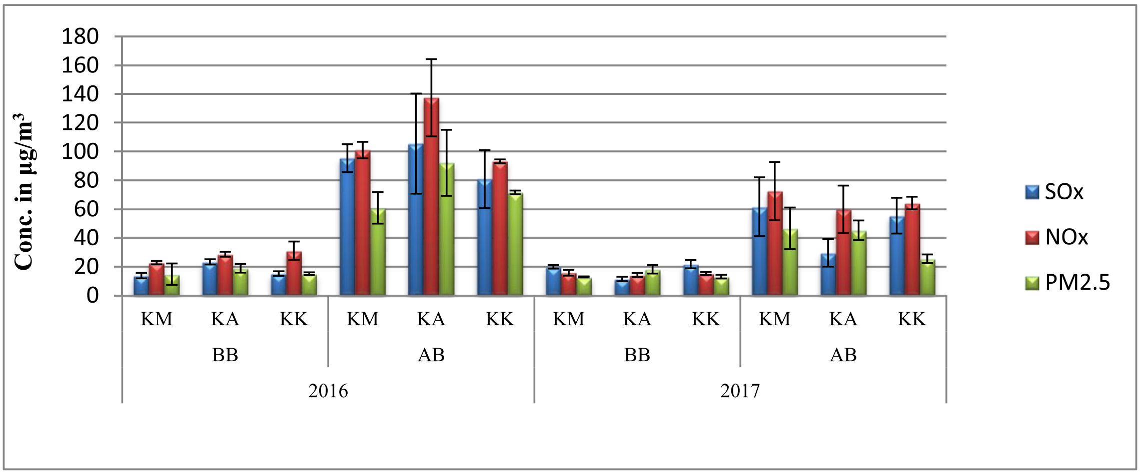

Fig. 3 Comparison in levels of SO_x, NO_x, and $PM_{2.5}$ (µg/m^3) during pre-burning and burning periods for rice residue in three districts of Haryana

2016 whereas in 2017, particulate matter was within the limits. During residue burning of wheat, $PM_{2.5}$ concentration was above the standards in all the three sites (KK, KA, and KM) in 2016 but in 2017, concentration of $PM_{2.5}$ was above the standards at KK site in Kaithal (Fig. 2c, f). Various factors have been reported to affect the ambient air quality parameters such as wind speed, humidity, wind direction, ambient temperature (Schultz 2002), the intermixing of pollutants derived from local origin and long-range transport mechanisms (Badarinath et al. 2009; Kumar et al. 2015). However, some other factors such as larger quantity of wheat residue generation, larger area under wheat residue burning, and accidental burning which were observed in present study may also be responsible for increased pollutant concentration in wheat season of the region. Lohan et al. (2017) reported that stubble of wheat alone contributed 57.31% and paddy contributed 21.17% to residue generation in Haryana. Yadav et al. 2014a reported more area under wheat residue burning (100.05 thousand hectares) as compared to rice (90.84 thousand hectares) in the three districts Kurukshetra, Kaithal, and Karnal. DTE (2017) also reported that the wheat crop residue burning is emerging as a major issue and complimentary factors behind the increase in crop residue burning in April–May, the spread of the wheat crop and mechanized farming. Therefore, reported findings also suggest that these factors may attribute to increase in pollutant concentration during wheat residue burning in that region.

Average pollutant concentration showed that KA was the most polluted area during rice burning season (Oct/Nov. 2016) with the maximum concentration of SO_x (105.44 ± 45.23 µg/m^3), NO_x (137.34 ± 34.94 µg/m^3), and $PM_{2.5}$ (72.46 ± 24.27 µg/m^3). However, in 2017, pollutant concentrations observed as reduced and were within standard limits as compared to year 2016 for all the sampling sites (Fig. 3). During wheat residue burning in 2016, maximum concentration of air pollutants was observed in KA site Karnal and in 2017 maximum pollutant concentration of SO_x (143.98 ± 41.03 µg/m^3), NO_x (107.3 ± 37.46 µg/m^3), and $PM_{2.5}$ (89.43 ± 21.99 µg/m^3) was observed at KK site in Kaithal (Fig. 4). Therefore, the results of the present investigation demonstrated that during rice residue burning in year 2016, maximum pollutant concentration was at KA site followed by KK and KM. And, in 2017, KM site in Kurukshetra district had maximum pollutant concentration followed by KA in

Fig. 4 Comparison in levels of SO_x, NO_x, and $PM_{2.5}$ (µg/m^3) during pre-burning and burning periods for wheat residue in three districts of Haryana

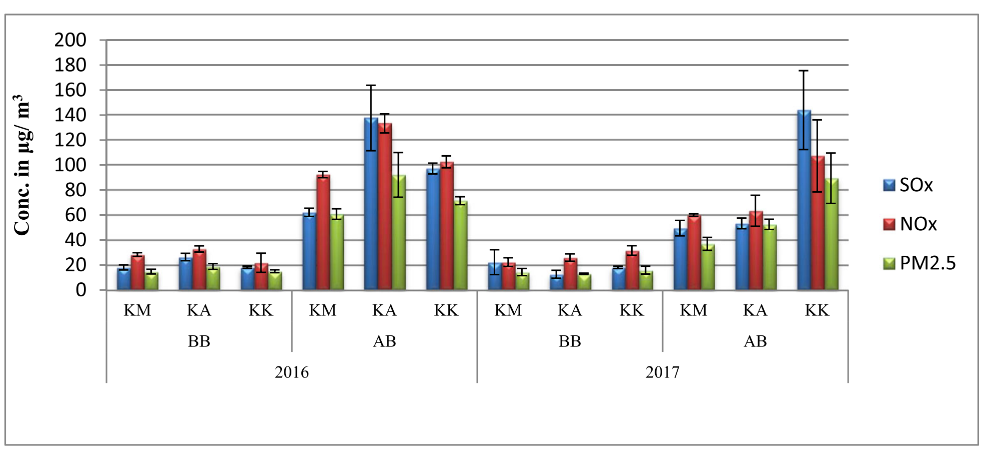

Table 3 Correlation analysis among pollutants concentrations of different crop, year, and region

Correlations

		SO_x	NO_x	$PM_{2.5}$	Year	Region	Crop
SO_x	Pearson correlation	1	.809	.847	− .544	.288	− .253
	Sig. (2-tailed)		.001	.001	.068	.363	.428
	N	12	12	12	12	12	12
NO_x	Pearson correlation	.809**	1	.766**	− .672*	.142	− .215
	Sig. (2-tailed)	.001		.004	.017	.660	.503
	N	12	12	12	12	12	12
PM2.5	Pearson correlation	.847**	.766**	1	− .415	.112	− .496
	Sig. (2-tailed)	.001	.004		.179	.729	.101
	N	12	12	12	12	12	12
Year	Pearson correlation	− .544	− .672*	− .415	1	.000	.000
	Sig. (2-tailed)	.068	.017	.179		1.000	1.000
	N	12	12	12	12	12	12
Region	Pearson correlation	.288	.142	.112	.000	1	.000
	Sig. (2-tailed)	.363	.660	.729	1.000		1.000
	N	12	12	12	12	12	12
Crop	Pearson correlation	− .253	− .215	− .496	.000	.000	1
	Sig. (2-tailed)	.428	.503	.101	1.000	1.000	
	N	12	12	12	12	12	12

Karnal and KK in Kaithal. During residue burning of wheat in year 2016, maximum concentration of air pollutants was observed in KA site Karnal and in 2017 maximum pollutant concentration of SO_x (143.98 ± 41.03 μg/m^3), NO_x (107.3 ± 37.46 μg/m^3), and $PM_{2.5}$ (89.43 ± 21.99 μg/m^3) was observed at KK site in Kaithal followed by KA and KM (Fig. 3b). It has been reported that the Kaithal district in which KK site falls has highest wheat residue burning area (26.83% of wheat area) followed by Karnal (21.67%) where KA site and Kurukshetra (14.53%) district where KM site was located (Yadav et al. 2014b). The overall pollutant concentration (SO_x, NO_x, and $PM_{2.5}$) in year 2016 was found to be more as compared to 2017, for both the crops and for all the study sites. The results of the present study are supported by the fact that 12826 fire points were observed in Kharif season in the year 2016 which decreased to 12417 in the year 2017 and the area under residue burning in 2016 was 45.11 thousand hectares, whereas in 2017, it was 39.6 thousand hectares in Haryana (HARSAC, 2017).

Correlation analysis

Correlation study was carried out to find the relation between increasing concentrations of SO_x, NO_x, and $PM_{2.5}$ over different years, crops, and regions. Positive and significant correlation values were observed between SO_x, NO_x, and $PM_{2.5}$ concentrations suggesting that increase in one's concentration positively affected the increase in others concentration ($p <$ 0.01). Furthermore, as the pollution level went down in 2017 as compared to 2016, negative correlation values were observed between years and all the three pollutants. Region and crop had no significant correlation with the pollutants (Table 3).

Air Quality Index

Air Quality Index (AQI) was employed to classify the hazard rating of the gaseous pollutants and particulate matter. The concentrations of the major pollutants were monitored and subsequently converted into the AQI (Table 4). The higher value of an index refers to a greater level of air pollution and consequently greater health risks. The AQI of the study sites revealed that during

Table 4 Air quality categories based on AQI

Category	AQI of ambient air	Description of ambient air quality
I	Below 10	Very clean
II	Between 10–25	Clean
III	Between 25–50	Fairly clean
IV	Between 50–75	Moderately polluted
V	Between 75–100	Polluted
VI	Between 100–125	Heavily polluted
VII	Above 125	Severely polluted

Source: CPCB, National Ambient Air quality Monitoring series, NAAQMS/22/2001-02 non-burning periods, all sites KA, KM, and KK lie in the range of fairly clean (AQI 25–50) category during both rice and wheat season while during burning periods these varied from moderately (AQI 50–75) to severely polluted (above 125) category. During rice season, KM was observed to be under category VI (heavily polluted) and KA came under AQI category VII (severely polluted). In wheat stubble burning period, KA in 2016 and KK in 2017 were under AQI category VII (severely polluted). Similarly in the corresponding period, AQI in capital region of Delhi NCR has been reported to be under "very unhealthy/severely polluted" category (Nasim 2015), with a continuous decline in the air quality.

Conclusions and recommendations

Assessment of ambient air quality at three study sites clearly indicated that there is a significant increase in concentration levels of $PM_{2.5}$, SO_x, and NO_x during crop residue burning period as compared to non-burning period. If compared with National Ambient Air Quality Standards (NAAQS), the average increase in SO_x, NO_x, and $PM_{2.5}$ concentrations was 25%, 37%, and 17% after stubble burning. The results depict the percent increase in SO_x being maximum during 2017 wheat season in KK site (Kaithal) and NO_x and $PM_{2.5}$ percent increase being maximum at site KA (Karnal) during 2016 rice residue burning. The overall pollutants concentration was observed to be maximum in KA (Karnal) followed by KM (Kurukshetra) and KK (Kaithal) during rice residue burning and during wheat residue burning the trend was KK (Kaithal) > KA (Karnal) > KK (Kurukshetra). The AQI (Air Quality Index) depicted that site KA in Karnal district was *severely polluted* during rice as well as wheat residue burning period in 2016. However, site KK in Kaithal district was observed to be *severely polluted* during 2017 after wheat residue burning. Thus, it can be concluded from the study that the residue burning caused great deterioration in the ambient air quality of Haryana and the overall concentration of all the pollutants in year 2016 was more as compared to 2017.

To combat the problem of crop residue burning, it is suggested that residue collection system should be initiated by Government or NGOs so as to collect residues from the fields and sell to industries for further utilization such as straw particle boards, or for composting, bricking, and pyrolysis, generation of energy by direct combustion, gasification, carbonization, ethanol production, liquefaction, or production of biofuel. Recycling in soil to manage the residues in a productive manner has been proposed by several scientists. These practices will help in management for improving soil health, increasing productivity, reducing pollution, and enhancing sustainability and resilience of agriculture.

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References

Agarwal R, Awasthi A, Nirankar S, Gupta PK, Mittal SK (2012) Effects of exposure to rice-crop residue burning smoke to pulmonary functions and oxygen saturation level of human beings in Patiala(India). Sci Total Environ 429:161–166

Badarinath K, Kharol SK, Sharma AR (2009) Long-range transport of aerosols from agriculture CRB in Indo-Gangetic Plains—a study using LIDAR, ground measurements and satellite data. J Atmos Sol-Terr Phy 71:112–120

Cheng Z, Wang SX, Fu X, Watson JG, Jiang JS, Fu QY, Chen CH, Xu BY, Yu JQ, Chow JC, Hao JM (2014) Impact of biomass burning on haze pollution in the Yangtze River delta, China: a case study in summer 2011, 20. Atmos Chem Phys 14:4573–4585

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Speizer FE (1993) An association between air pollution and mortality in six US cities. N Engl J Med 329:1753–1759

Ercoli L, Aduini I, Mariotti M, Lulli L, Masoni A (2012) Management of sulfur fertilization to improve durum wheat production and minimize leaching. Eur. J. of Agron 38:74–82

Gadde B, Bonnet S, Menke C, Garivait S (2009) Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environ Pollut 157:1554–1558

Grover D, Kaur P, Sharma HR (2015) Possible reasons and farmers awareness towards crop residue burning: an overview and a case study from Mirzapur Village of Kurukshetra District, India.. EnvironWe IntJSciTech 10:75-85

Gurjar BR, Ravindra K, Nagpure AS (2016) Air pollution trends over Indian megacities and their local-to-global implications. Atmos Environ 142:475–495

Guttikunda SK, Jawahar P (2014) Atmospheric emissions and pollution from the coalfired thermal power plants in India. Atmos. Environ 92:449–460

Gyawali C, Dahiya DS, Devraj BMA, Bhandari R (2016) Spatial distribution of physico-chemical properties and macronutrients in rice growing soils of Haryana. The Ecosan 10:365–370

Hays M, Fine P, Geron C, Kleeman M, Gullett B (2005) Open burning of agricultural biomass: physical and chemical properties of particle-phase emissions. Atmos Environ 39:6747–6764

He QS, Zhao XY, Lu J, Zhou GQ, Yang HQ, Gao W, Yu W, Cheng TT (2015) Impacts of biomass-burning on aerosol properties of a severe haze event over Shanghai. Particuology. 20:52–60

Huang KH, Fu JS, Hsu NC, Gao Y, Dong X, Tsay SC, Lam YF (2012) Impact assessment of biomass burning on air quality in Southeast and East Asia during BASE-ASIA. Atmos Environ 78:291–302

Jacobs MB, Hochcheiser S (1958) Continuous sampling and ultra microdetermination of nitrogen dioxide in Air. Anal Chem 30: 426–428

Jain N, Bhatia A, Pathak H (2014) Emission of air pollutants from crop residue burning in India. Aerosol Air Qual Res 243(14):422–430

Jarvan ML, Eldesi A, Adamson L, Lukme AA (2008) The effect of sulfur fertilization on yield, quality of protein and baking properties of wheat. Agron.Res. 6:459–469

Jitendra, Venkatesh S, Kukreti I, Pandey K, Niyogi DG, Mukerjee P (2017) India's burning issue of crop burning takes a new turn. DTE. Retrieved from http://www.downtoearth.org.in/coverage/river-of-fire - 57924

Kaur J, Cihacek LJ, Chatterjee A (2018) Estimation of nitrogen and sulfur mineralization in soils amended with crop residues contributing to nitrogen and sulfur nutrition of crops in the North Central US. Commun Soil Sci Plant Anal 49(18):2256–2266

Khandbahale DS and Saler RS (2013) Ambient Air Quality Monitoring in Nashik city (Maharashtra, India). Bionano Frontier. Vol. 6 : July – December

Kharol SK, Badarinath KVS (2006) Impact of biomass burning on aerosol properties over tropical urban region of Hyderabad, India. Geophys. Res. Lett 33

Kumar R, Barth MC, Pfister GG, Nair VS, Ghude SD, Ojha N (2015) What controls the seasonal cycle of black carbon aerosols in India? J Geophys Res Atmos 120:7788–7812

Lohan SK, Jat HS, Yadav AK, Sidhu HS, Jat ML, Choudhary M, Peter JK, Sharma PC (2017) Burning issues of paddy residue management in north-west states of India. Renew Sust Energ 81:693–706

Mishra AK, Shibata T (2012) Synergistic analyses of optical and microphysical propertiesof agricultural crop residue burning aerosols over the Indo-Gangetic Basin (IGB). Atmos. Environ. 57, 205–218Mittal SK, Singh N, Agarwal R, Awasthi A, Gupta PK (2009) Ambient air quality during wheat and rice crop stubble burning episodes in Patiala. Atmos Environ 43:238–244

Mishra AK, Chaudhari SK, Kumar P, Singh K, Rai P, Sharma DK (2014) Consequences of straw burning on different carbon fractions and nutrient dynamics. Indian Farming 64:11–12

NAAQS (2009) National Ambient Air Quality Standards. Central Pollution Control Board, New Delhi (India) Notification, November 18, 2009

Nasim U (2015) Paddy fields burning: smog shrouds national capital; Down To Earth. https://www.downtoearth.org.in/news/air/burning-paddy-fields-deteriorate-air-quality-in-delhi-51687. Accessed 07 Dec 2015

Panigrahy S, Hooda RS, Ray SS, Yadav M, Manjunath KR, Sharma MP, Parihar JS (2008) Cropping system analysis using remote sensing & GIS: Haryana state. Technical Report: EOAM/SAC/CS/SN/02

Peters A, Von Klot S, Heier M, Trentinaglia I, Hörmann A, Wichmann HE, Löwel H (2004) Exposure to traffic and the onset of myocardial infarction. New England J Med 351(17):1721–1730

Ram A, Kumar D, Singh N, Anand A (2014) Effects of sulphur on growth productivity and economics of aerobic rice (oryza sativa). Indian J Agron 59:404–409

Randall PJ, Freney JR, Spencer K (2003) Diagnosing sulfur deficiency by grain analysis. Nutr Cycl Agroecosyst 65:211–219

Schultz MG (2002) On the use of ASTR fire count data to estimate the seasonal and interannual variability og vegetation fire emissions. Atmos. Chem. Phys. Discuss 2:1159–1179

Sidhu R, Bansal M, Bath GS, Garg R (2015) Impact of stubble burning on the ambient air quality. Int. J Mech Prod Eng 3:46–50

Singh Y, Sidhu HS (2014) Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic Plains of India. Proc Indian Natn Sci Acad 80:95–114

Singh N, Mittal SK, Agarwal R, Awasthi A, Gupta PK et al (2010) Impact of rice crop residue burning on levels of SPM, SO_2 and NO_2 in the ambient air of Patiala (India). Int J Environ Anal Chem 90:829–843

Tiwari TN, Ali M (1987) Air Quality Index for Calcutta and its monthly variation for various localities. Ind J Environ Protect 7:172–176

Tripathi S, Singh RN, Shaisav S (2013) Emissions from crop/biomass residue burning risk to atmospheric quality. Int Res Earth Sci 124:30

Venkataraman C, Habib G, Kadamba D, Shrivastava M, Leon JF, Crouzille B, Streets DG (2006) Emissions from open biomass burning in India: integrating the inventory approach with high-resolution Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data. Global Biogeochem Cy 20:1–12

West PD, Gaeke GC (1956) Fixation of sulphur dioxide as sulfitomercurate (II) and subsequent colorimetric estimation. Anal Chem 28:1816–1819

Yadav M, Prawasi R, Satyawan, Rana P, Kumari K, Lal S, Karamdeep, Siddarth and Hooda, RS (2014a) Area estimation of paddy stubble burning in ten major paddy growing of Haryana. Technical Report: HARSAC/TR/01/2014, pp 28

Yadav M, Sharma MP, Prawasi R, Khichi R, Kumar P, Mandal VP, Hooda RS (2014b) Estimation of wheat/rice residue burning areas in major districts of Haryana, India, using remote sensing data. J Indian Soc Remote 42:343–352

Zhang HF, Ye XN, Cheng TT, Chen JM, Yang X, Wang L, Zhang RY (2008) A laboratory study of agricultural crop residue combustion in China: emission factors and emission inventory. Atmos Environ 42: 8432–8441

Zhang LB, Liu YQ, Hao L (2016) Contributions of open crop straw burning emissions to PM2.5 concentrations in China. Environ Res Lett 11. https://doi.org/10.1088/1748-9326/11/1/014014,2016b

Zhao FJ, Salmon SE, Withers PTA, MonaghanJ M, Evans EJ, Shewry PR, McGarth SP (1999) Variation in the bread making quality and rheological properties of wheat in relation to sulphur nutrition under field conditions. J Cereal Sci 30:19–31