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Transboundary Air Pollution in Bangladesh: Impact of Post-Harvest Crop Residue Burning of Rural Indo-Gangetic Plains

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Abstract

The post-harvest agricultural residue burning in Indo-Gangetic Plains (Punjab, Haryana), starting at the end of October and November, raises severe air pollution problems for the regional areas. Due to the proximity to India, border areas of Bangladesh have a high chance of getting air pollutants with the transported air masses from these regions because of favourable wind directions. This study took Rajshahi as the study area for identifying transboundary air pollution from the Indo-Gangetic Plains (IGP). During the study period (October to December 2018) PM 2.5 and PM 10 concentrations (95±32.5 μg/m^3 and 195.4±71.6 μg/m^3 respectively) were around 2 times and 1.5 times higher than NAAQS. The satellite-based fire counts from FIRMS showed a high number of fire incidents (>6000) mainly occurred from 27 October to 8 November and Bangladesh has lower than 200 throughout the period. Daily 96 hours of air mass back trajectory and cluster analysis using the HYSPLIT-5 model resulted in 5 clusters for the study period. The C1 and C2 are identified as the main contributors to transboundary air pollution in Rajshahi. The clusters C1 and C2 mainly carried air masses with PM 2.5 from IGPs, Uttar Pradesh, and Delhi and contributed to an increase of more than 35% of PM 2.5 concentration during the crop burning period.

Keywords: Transboundary Air Pollution, PM 2.5, PM 10, HYSPILT, FIRMS, Crop Burning, Bangladesh.

1. Introduction

Apart from the local anthropogenic sources emitting particulate matter (PM) into the atmosphere, cities often receive pollutants from regional activities. The transport of air pollutants from other areas is known as Transboundary Air pollution (TAP) which is given lesser attention by the media and policymakers [1-3]. PM 2.5 (having an aerodynamic diameter of less than 2.5μm) can travel longer distances from its originating source. Thus, highly polluting areas not only deteriorate their air quality but also have impacts on the air quality of neighboring areas [4]. Crop residue burning in Indo-Gangetic Plains (IGPs)-Punjab, Haryana, Uttar Pradesh- found to release a huge amount of PM in the atmosphere estimated at 824 Gg per year [5]. The post-harvest crop burning in these areas starts mainly after monsoon from the last week of October and continues up to the last days of November [6-7]. Several studies found the impact of this crop burning in neighboring areas. Delhi often experiences severe air quality, and haze events because of the post-harvest burning [3]. It has been observed that on peak days, burning contributes a 50-70% increase in PM 2.5 concentration in these areas. Because of lower temperatures and wind speeds in post-monsoon and winter seasons, inversion and stable atmospheric conditions trap the particulate loads closer to the ground causing huge haze and poor air quality [6]. As Bangladesh is proximate to the IGPs of India and westerly and north-westerly wind mainly prevails during this period, the border areas are more susceptible to receiving PM loads from post-harvest crop burning from these areas [1][8]. Rajshahi, one of the border areas of Bangladesh, is non-industrialized and has fewer local pollutant-emitting sources. However, during the post-monsoon and winter seasons, it experiences poor air quality. Very few studies are available to assess the potential impact of post-harvest burning transboundary impact in Rajshahi.

This study investigates the probable route through which air can carry PM to Rajshahi and the extent to which this area receives PM 2.5 from IGPs. HYSPILT-based back trajectories, PM 2.5 and PM 10

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characteristics assessment, and satellite-based FIRMS fire counts were intricate to differentiate the local and transboundary impacts, finding out the routes of the air parcel and extent of PM 2.5 loading due to burning. As few studies are available in Bangladesh to address this issue, authors believe this study will pave further research and attention in this field.

2. Materials and Methods

2.1 Air and Fire Count Data Sources

The PM-2.5 and PM-10 data is collected from the Continuous Air Monitoring Stations (CAMS) under the CASE project of the Department of Environment (DoE), Bangladesh [9]. The pollutants data are taken hourly basis from October 1 October 2018 to 31 December 2018. This period is divided into three parts- Pre burning (1 October to 20 October), Burning (21 October to 20 November), and Post burning (21 November to 31 December). The study period is taken considering the period of agricultural harvesting, residue burning, and fertilizer spraying activities that take place in IGPs [3][6-7]. Necessary data preprocessing cleaning, missing data fill, and outliers cleaning- are done following standard practices in MATLAB. The satellite-based active fire count data for this study period is extracted from the Fire Information for Resource Management System (FIRMS) standard which has a Visible Infrared Imaging Radiometer Suite (VIIRS) sensor from NASA/NOAA Suomi-National Polar-orbiting (Suomi NPP) satellite https://firms.modaps.eosdis.nasa.gov/. The fire count data are available within 3 hours of the incident [10].

3. Methodology

3.1 Study Area

Rajshahi was chosen for the study location. It is located North-western part of Bangladesh. It is 23 meters above sea level, around 2400 km^2 area, and has a tropical wet and dry climate. It is one of the hottest locations in Bangladesh having on average 32-36°C of mean highest temperature. Rajshahi has the overall same climatic condition as Bangladesh having Pre-monsoon (March-May), Monsoon (June-September), Post-monsoon (November-April), and winter (December-February) [11]. This particular location was chosen because of comparatively lower local pollution incidents, no heavy industry, and proximity to the Indian border. The CAMS-9 station is located at Sopura (24.38 N, 88.61E) from where the PM-10 and PM-2.5 concentrations are collected [9]. For finding active fire counts in the IGP, the study area covered Haryana, Punjab, and the proximate areas of the IGP.

3.2 Trajectory and Cluster Analysis

HYSPILT (v 5.2.1, 2023) is used for simulating 96 hours of backward trajectory analysis starting at 250 meters above the ground level from the study location (24.38 N, 88.61E) [12]. The trajectories are calculated every 6-hour interval during the whole study period identifying the 96-hour previous pathway of the air masses that is received at the location. The GDAS1 (Global Data Assimilation System, horizontal resolution 1°) data from the global reanalysis data archive of NOAA was used for the input meteorology of the HYSPLIT model for the calculation of trajectories.

Cluster analysis was also done with the HYSPLIT software based on the proximity of latitude and longitude that the trajectories travel. The change of total spatial variance of the clusters with the probable cluster no is used to find out the optimum cluster no for the given set of trajectories [13].

3.3 Probability and Statistical Analysis

The probability of the trajectories under clusters to receive a certain amount of pollution ending in the study location is calculated according to [8]

$$P(cx) = \frac{N(cx)}{N(c)}$$

Here, *P(cx)* = Probability of trajectories under cluster *C* to carry PM-2.5 concentration greater than x; *N(cx)* = Number of trajectories under cluster *C* associated with PM-2.5 concentration greater than x. *N(c)* = Number of total trajectories under cluster *C*. The descriptive statistical analysis of concentration data was done in MATLAB.

4. Results and Discussion

4.1 Fire Count Analysis

Agricultural crop burning mainly starts in mid-October in the villages of the IGPs. Figure 1(a, b) shows the total fire incidents that occurred during the study period and also the number of fire incidents in Bangladesh. During pre-burning (PB) and post-burning periods (PoB), the number of fire incidents was lower (>200) throughout the selected areas combined. However, there was a huge rise in total daily fire counts after 20 October and reached a maximum of 10758 fire incidents on 7 November 2018. A high number of fire incidents (>6000) mainly occurred from 27 October to 8 November. But during this study period, Bangladesh and mainly Rajshahi had very low fire incidents having total counts below 200

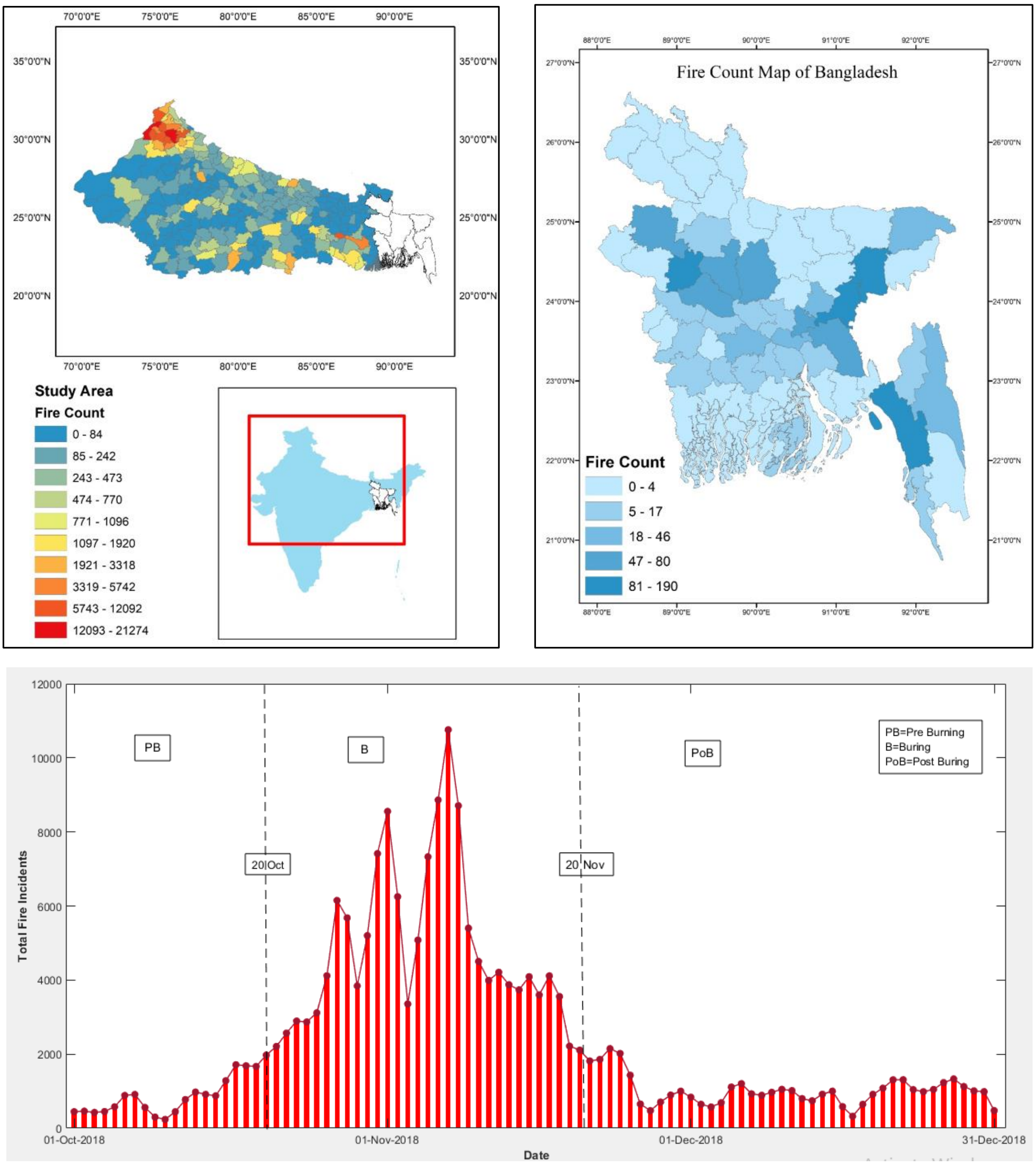


Fig. 1: (a) The study area, Total fire counts in the neighboring areas of the study location covering the IGPs. (b) The total fire incidents in Bangladesh. (c) Daily Fire counts throughout the study period.

incidents. This proves that the local areas of Bangladesh don't burn the agricultural biomass during or post-harvesting periods.

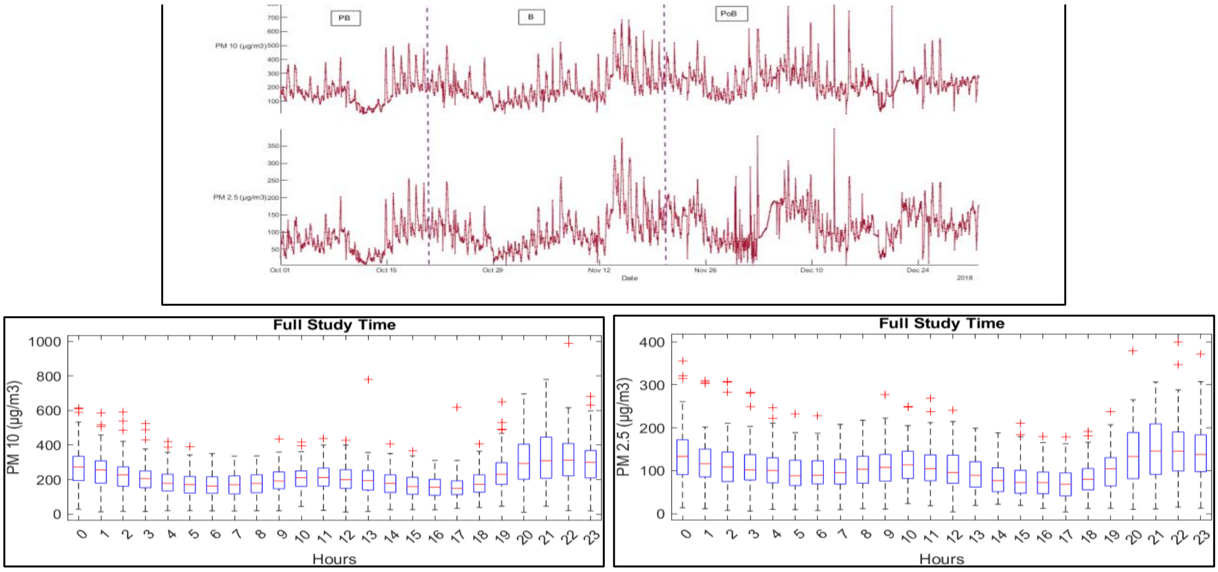
4.2 Trends of PM 2.5 and PM 10 Pollution

In general, the Megacities of Bangladesh experience huge pollution loads during the winter season. But the pollution is comparatively lesser in other major cities compared to Dhaka and it's proximate cities. However, during this study period, Rajshahi had a higher PM concentration than the NAAQS (150 $\mu g/m^3$ for PM10 and 50 $\mu g/m^3$ for PM 2.5). Average PM 2.5 and PM 10 loads were 95±32.5 $\mu g/m^3$ and 195.4±71.6 $\mu g/m^3$ respectively which is around 2 times and 1.5 times higher than NAAQS. Figure 2(a) shows the time series concentration profiles of PM pollutants during the study periods in Rajshahi. The diurnal variation of PM concentration during the study periods shows the increase of the PM loads from the evening and stable high concentration during the night time which eventually drops in the morning. Lower temperature, lower boundary layer, and low wind create a stable atmosphere which eventually holds the higher PM during the night time.

This nature of PM pollution is a general trend for the winter season. However, during PB the pollution loads were comparatively lower than the B and PoB. Daily concentrations during the three periods were 73±28, 92.6±14, 125.1±39.25 μg/m^3 for PM 2.5 and 165±60.2, 187.44±70.55 and 243.22±87.13 μg/m^3 for PM 10 respectfully. A huge rise in PM loads was observed last part of burning and the first part of PoB. When fire incidents raised after 5 November, the pollution loads in the Rajshahi also increased significantly after 10 November. Thus, it signifies

the probable impact of the transportation of PM after the agricultural residue burning stated in the IGPs.

Fig. 2: PM 2.5 and PM 10 pollution characteristic during the study period. (a) Time series concentration profile of PM 10 and PM 2.5. (b) Diurnal variation of PM concentration



4.3 Trajectories and Cluster Analysis

A total of 342 trajectories were found to carry the air masses that ended up in the Rajshahi throughout the study period. The trajectories were clustered into 5 groups based on the minimum spatial variances. Figure 3(a) shows the mean clusters that are obtained and the percentage of trajectories under each cluster. Clusters 3 and 4, which correspond to 19 and 26% of total trajectories mainly, are associated with the air within the country and areas closer to the Rajshahi and also these trajectories brought air masses to the location traveling below 1000 m. From the closer observation of full trajectories, C3 and C4 are mainly local winds and can carry pollutants from local sources having lower boundary layers. Cluster 5 mainly brought air from the southern, and south-eastern parts of the country, and its abundance is comparatively lower. Thus C3, C4, and C5 can be considered as local contributors. However, the C1 and C2 traveled a longer distance before bringing air masses to Rajshahi. C1 brought air masses from the northern, and north-western parts of India (Delhi, Haryana, Punjab, Rajasthan) and the north-eastern part of Pakistan. These areas are considered as IGPs and from Figure 1(a), it is evident that these areas are highly associated with post-harvest agricultural residue burning. C2 also covered some areas of IGPs, Bihar and Uttar Pradesh. Thus, from cluster analysis, it is observed that air masses associated with C1 and C2 are more likely to bring PM loads from post-harvest burning areas. However, the contribution from C2 increased during the burning and post-burning periods (Figure 4) and air masses from C1 clusters remained almost the same in three time periods. Local air circulation (C4) also increased during the periods and air masses from C3 and C5 became almost zero during post-during the periods. and air masses from C3 and C5 became almost zero during post-burning.

4.4 Identification of Extent of Transboundary PM Transport and Pathway

The mean PM 2.5 association of C4 and C5 during the pre-, burning, and post-burning time remained almost the same and no large increase in PM concentration was observed (Table 1). These brought a lower amount of PM to the Rajshahi and were not associated with the post-harvest burning transboundary pollution. The PM 2.5 concentration of C3 increased slightly during the burning period and significantly higher during post-burning time. As C3 is more distributed over the Rajshahi itself and trajectories are below 1000m, it can be the impact of local sources. During winter, dust and vehicular transport contribute to the local PM loads. Thus, the C3 is more prone to be associated with local

PM emission. A significant increase of PM 2.5 is found for C1 and C2 during the burning and post-burning time (Table 1). C1 bought two times higher PM 2.5 in burning time and also the initial time of post burning period. It has an overall 50% probability of bringing PM 2.5 to Rajshahi with a concentration of more than 100 µg/m^3. C2 was initially associated with 100.88 µg/m^3 which increased to 136.46 µg/m^3 during the burning period. As C2 has some trajectories over Rajshahi, initially it contained local PM 2.5 too compared to C1. But C2 brought around 35% PM 2.5 to the station when agricultural burning was started. It is also to be noted that, there is no rapid rise of PM 2.5 loads during post burning period implying that the transboundary impact due to crop burning stopped during this period. The local contribution can be clearer from PM 2.5 to PM 10 ratios. These ratios remained almost the same for C3, C4, and C5 during three periods (Table 1) proving these trajectories are more associated with local emission. Whereas, PM2.5/PM 10 of C1 and C2 increased significantly (40% and 16% respectively) during the burning period but not so much during post burning session. It has been found that crop burning contributed to 40% of PM 2.5 loads [14]. Similar trends were also observed for crop burning in the IGPs [3][6]. Thus, it is clear that C1 and C2 brought a significant amount of PM 2.5 to the Rajshahi due to post-harvest crop burning in IGPs and their air masses traveling pathways are the main route for transboundary PM pollution in Rajshahi.

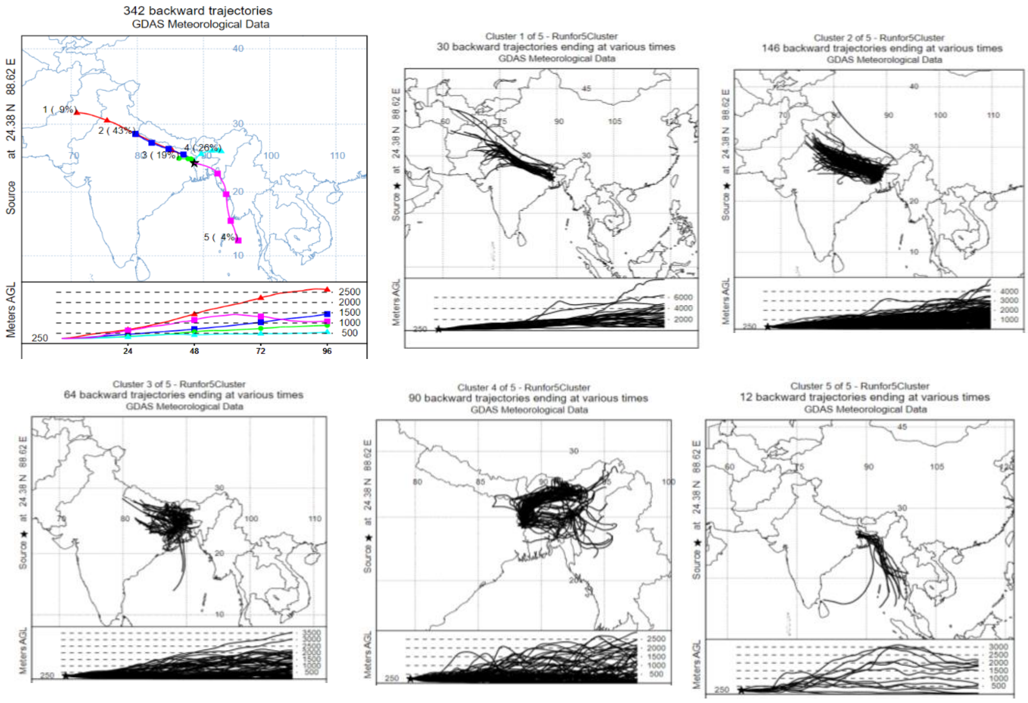


Fig 3: 96 hours back trajectories ended up Rajshahi throughout the study period. The starting point was 250 m above ground level. (a) Mean clusters of 342 trajectories. (b) Individual trajectory profiles of the clusters.

Cluster No.	Transport Pathway	PM 2.5 Association (PB, B, PoB)	% Probability of getting PM 2.5 (µg/m^3)		PM 2.5/PM 10 ratio (PMB, B, PoB)	Rank in terms of	
			>50	>100		Pollution Load	Lang Range Transport
C1	Mainly from the north-eastern and western part of India covering Bihar, Uttar Pradesh, Delhi, Haryana, Punjab, and some northeastern parts of Pakistan	54.35±18.40 107.58±61.68 117.6±37.01	86.67	50.0	0.36 0.50 0.51	High	High

C2	Concentrated in the northeastern and western parts of India. Covering Bihar, the northern part of Uttar Pradesh, Delhi and Haryana, Uttarakhand, and also the Himalayan parts of Nepal.	100.88±31.70 136.46±61.68 146.19±42.51	100.0	71.43	0.44 0.51 0.54	High	Moderate
C3	North, north-western part of Bangladesh. Covers some parts of Bihar, Sikkim, Jharkhand, and West Bengal.	95.67±45.08 102.30±27.58 138.18±39.33	95.24	52.38	0.49 0.50 0.51	High	Low
C4	Mainly from north northeastern part of Bangladesh, some parts of Sikkim, Meghalaya, and Assam.	79.87±27.41 74.31±35.60 98.43±38.12	85.56	34.44	0.46 0.48 0.49	Moderate	Low
C5	The south and southwestern part of Bangladesh, some marine routes of the Bay of Bengal.	34.68±17.27 42.19±1.01	8.33	--	0.44 0.42 --	Low	Low

Table 1: A summary table containing the transport pathways of the trajectories, associated PM loads, ratio of PM 2.5 to PM 10 during pre-, burning, and post-burning periods, probability of PM 2.5, and ranking for the transboundary impact of the clusters.

5. Conclusion

The post-harvesting crop burning releases lots of primary pollutants in the atmosphere which eventually form harmful secondary pollutants and PM 2.5. Bangladesh, especially areas closer to India is more prone to receive PM 2.5 through transboundary air pollution. This study evaluated the potentiality of PM 2.5 loads in Rajshahi due to post-harvest crop residue burning that takes place in IGPs. Both PM 2.5 and 10 were found to be higher than national standards and also were found to be comparatively higher during the burning period. Air masses that are ended up in Rajshahi traveling over IGPs during the study period are analyzed and the Uttar Pradesh found to increase PM 2.5 loads in

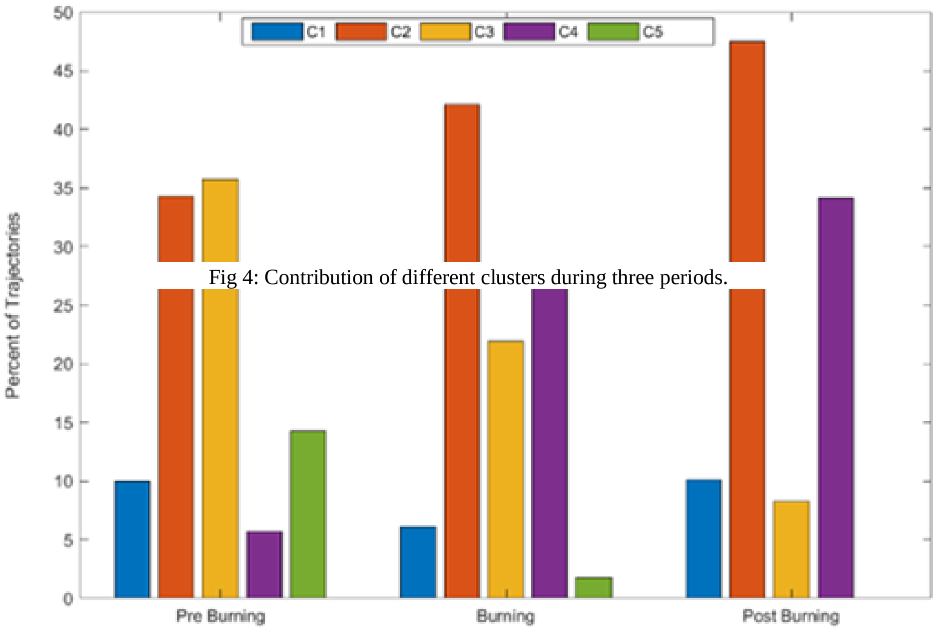


Fig 4: Contribution of different clusters during three periods.

Rajshahi by more than 35% during the burning period. Thus, this study concludes that the areas closer to the border with India received a large extent of PM from 20 October to 20 November due to crop burning which resulted in large air quality deterioration in these areas.

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