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Research Article
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Travelling and Source Point Identification of Some Transboundary Air Pollutants by Trajectory Analysis in Sathkhira, Bangladesh

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Abstract: Trajectory of transboundary air pollutants are studied in Satkhira district through HYSPLIT Model4. Atmospheric pollutants data and meteorological data collected from Department of Environment (DoE) and Bangladesh Meteorological Department (BMD) are used in this study. The pollutants are collected with passive sampler and analyzed through suitable analytical methods. Atmospheric air pollutants data were studied from December 2005 to April 2007. It is found that the level of SOx is much higher in the dry (December to February) season than wet season. The highest concentration of SOx and NOx observed during the month of February 2006 and December 2006 (13 µg/m^3), and January and February 2007 (7 µg/m^3). During November, December of the year 2006 and January, February, March of the year 2007 pollutants concentration is estimated at increased level. The application of SOx to NOx ratio depicts that during dry season power plant and coal burning is the major source of these pollutants, but in wet season they are mainly from vehicular emission of the Bay of Bengal. Backward air mass trajectory showed that the level of SOx and NOx increase when there is an air mass movement over India (North and North West) and fall when the trajectories spend most of their 5day time over Bay of Bengal. It is evident from the study that transboundary traveling has a significant effect on air quality and the pollutants traveled firmly beyond the boundary line of Bangladesh.

Keywords: Transboundary Air Pollution, NOx, SOx, Atmospheric Pollutants, Trajectory Analysis

1. INTRODUCTION

Transboundary air pollution, i.e., pollution generated in one country with impacts in others, is now

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considered as a major problem in many countries of the world. Most of the present researches relating to atmospheric chemistry are concerned of transboundary air pollution because of its inevitable effects on human health and significant role in climate change. European and North American countries have made marked progress in transboundary air pollution research. Most of these researches are concerned with the transport of pollutant from Asia to North America mostly from China and East Asia as these regions are rated as the rising economic developed countries and industrial emissions have been increasing along with emissions associated with land cleaning and agriculture [1-6]. Being very close to two most rapid growing industrial country of the world namely China and India, Bangladesh may be a victim to transboundary air pollution. NOx are emitted primarily by motor vehicles making it as strong indicators of vehicles emission [7] on the contrary SOx are mainly emitted from coal burning industries and power plants. A significant number of power plants and coal mines situated near the Bangladesh Border and the Vehicles ply in the Bay of Bengal could be the source of NOx.

Inorganic air pollutants (SOx and NOx etc.) are of major health concern mainly due to their carcinogenic properties. It could enhance the effect of allergens, Bronchial reactivity and respiratory diseases [7]. Moreover Sulphur dioxide and Nitrogen dioxides are the main cause of acid rain [8]. These adverse properties demand an assessment of their trends and source profile in the atmosphere to provide an aid to manage regional and local as well as global air pollution strategies [9-10].

Air Pollution related works in Bangladesh are few and most of them are focused to the air quality and characterization of the air pollutant in the capital city Dhaka [11-21]. Salam *et al.* [19] performed the chemical characterization of aerosol in the district Bhola one of the remote island of Bangladesh. Begum *et al.*, [17] discussed the key issues in controlling air pollution in the capital city Dhaka. But there is no research in the country concerning the transboundary air pollution of Bangladesh. However, Begum et al., [12] presumed that the pollutant level of Dhaka city in winter may be caused by transboundary air pollution.

Air mass trajectories provide a useful means of establishing source receptor relationships of air pollutants [22-23]. Pollutant emitted from various source can remain in the atmosphere sufficiently long to be transported thousands of kilometers and thus to spread over a large area across national borders, far from the original source of polluting emissions [24]. Moreover there are many studies which confirm that the general atmospheric circulation leads to long range transport of aerosol or suspended particulate matter (SPM) over varying regions of the world [25-27]. That is why atmospheric trajectories could be a useful means to monitor the transboundary air pollution. Many authors used trajectory modeling to identify the source and pathways of pollutant transport [24, 28-29]. This paper provides information on the seasonal variability of pollutant in the Sathkhira monitoring station of Bangladesh and investigation was made to see the episode nature of transboundary transport of SOx and NOx.

2. MATERIALS AND METHODS

2.1 Study Area

The Sathkhira monitoring station(22o18' N & 89o02' E) is located (Figure 1) in the south-western part of Bangladesh approximately 450 km away from the capital city Dhaka and about 30 km north of the Sundarban forest. Sathkhira is chosen because there are no heavy industries in the region and limited number of vehicle ply in the road but a remarkable seasonal fluctuation of atmospheric pollutants is observed. Moreover, neighboring India has a large number of coal based power plants, thermal power plants and other heavy industries adjacent to the western, northwestern and southwestern boundary lines

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of Bangladesh. That is why monitoring of transboundary pollution could be fruitful by analyzing data of this station.

2.2 Collection of Samples

Passive sampler technique [30] has been used to collect air quality data. The passive sampler technique is very attractive in regional scale air quality monitoring because it is inexpensive, easy to use and do not require electricity to operate [30]. The samples from passive samplers were analyzed in their respective laboratories using suitable analytical methods such as Ion Chromatography (IC), Atomic Absorption Spectrometry (AAS), and Gas Chromatography (GC) etc. for specific pollutants. For the analysis of samples collected with passive samplers, samples are repacked in their containers at the end of sampling interval and sent to IVL-Swedish Environmental Research Institute Ltd. for analysis.

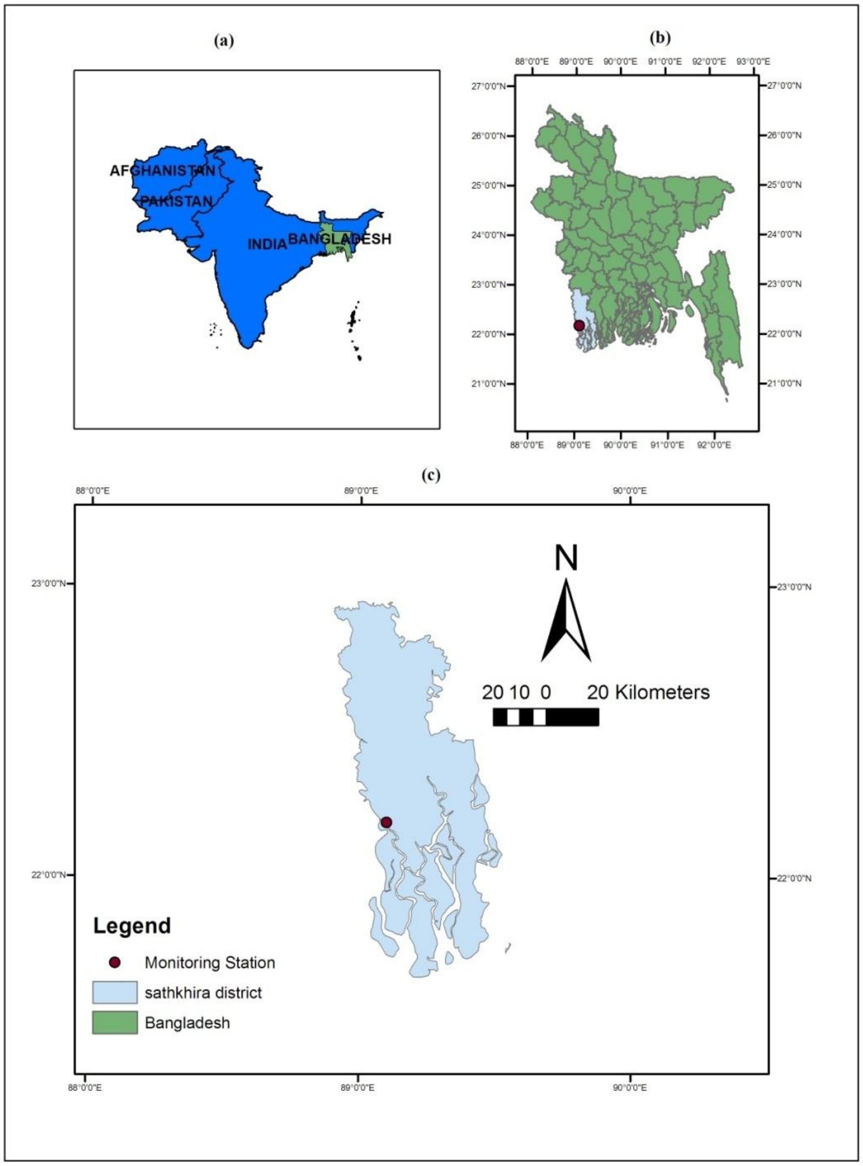

Figure 1. (a) Location of Bangladesh in the Indian sub continent (b) Sathkhira district and monitoring station in Bangladesh map (c) location of monitoring station in Sathkhira district map.

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2.3 Meteorological Dataset

Meteorological datasets were obtained from Bangladesh Meteorological Department (BMD). The BMD data consist of 3hr interval meteorological data (wind speed, direction, temperature, relative humidity) at standard pressure level. The 3h interval BMD data were interpolated linearly in time and space to generate average daily and monthly meteorological data set.

2.3 Wind Field and Backward Trajectory Analysis

Air mass trajectories were calculated according to HYSPLIT 4 model. The trajectory drawing principle of HYSPLIT 4 is based on the integration of the position of air mass with regard to time. Since air mass is transported with the help of the wind, its passive transport may be calculated evaluating three-dimensional means of speed vector when the particles are in the primary position P(t) and the first approximate position P′(t + dt). Details of the backward trajectory analysis can be found in Draxler et al., [31].

3. RESULTS AND DISCUSSION

Understanding the effects of weather events on the transport and formation of pollutants is crucial for the assessment of local or regional air quality. Being released into the air, air pollutants apparently become part of the composition of the atmosphere. Strong winds may take air pollutants away from their sources. Thus, drawing of wind patterns can tell us where pollutants are to travel [8]. It is a two step process; firstly, the temporal variations of the pollutant are compared with the meteorological condition of the monitoring station except wind direction and then correlation is made with wind direction and pollutant concentration. As air flow pattern can assess the transport pathways of traces, diagnosis can also be made to find out the source and receptor relationship [8, 32-33].

3.1 Observation at Sathkhira Monitoring Station

Maximum and minimum concentration value of SOx and NOx along with mean and standard deviation are shown in table 1. The difference between the maximum concentration of SOx and NOx were higher than their average concentration. The monthly variations in SOx showed high concentration (>4 μg/m^3) during December to March (Figure 2a). The concentration of SOx from December 2005 to January 2006 showed an increase up to 5.4μg/m^3. The concentration from January 2006 to February 2006 observed a steep increase reaching a maximum of 13 μg/m^3 and after that followed a declination to reach at 1.1μg/m^3 in May 2006. The concentration of SOx has reached in its minimum value in the month of September 2006 (0.8 μg/m^3). After that concentration of SOx took a sharp increase to reach its second maximum at February 2007 to 10μg/m^3. *Murano et al.*, [28] studied the Air pollution level in two remote island of Japan. According to their study the daily mean, maximum and minimum concentration of SOx were 3.23, 11.30 and 0.319 μg/m^3 respectively in OKI Island and for Okinawa Island these values were 2.78, 6.97 and 0.146 μg/m^3 accordingly. In the same way the daily average concentration of NOx in Oki Island was 1.310 μg/m^3 and in Okinawa Island it was 0.997 μg/m^3.

Table 1. Average, Maximum, Minimum and Standard deviation of the SOx and NOx concentration in the Sathkhira Monitoring station.

	SOx (μg/m^3)	NOx (μg/m^3)
Average	3.84	3.4222
Maximum	13	7
Minimum	0.8	1
Standard Deviation	3.42	2.13

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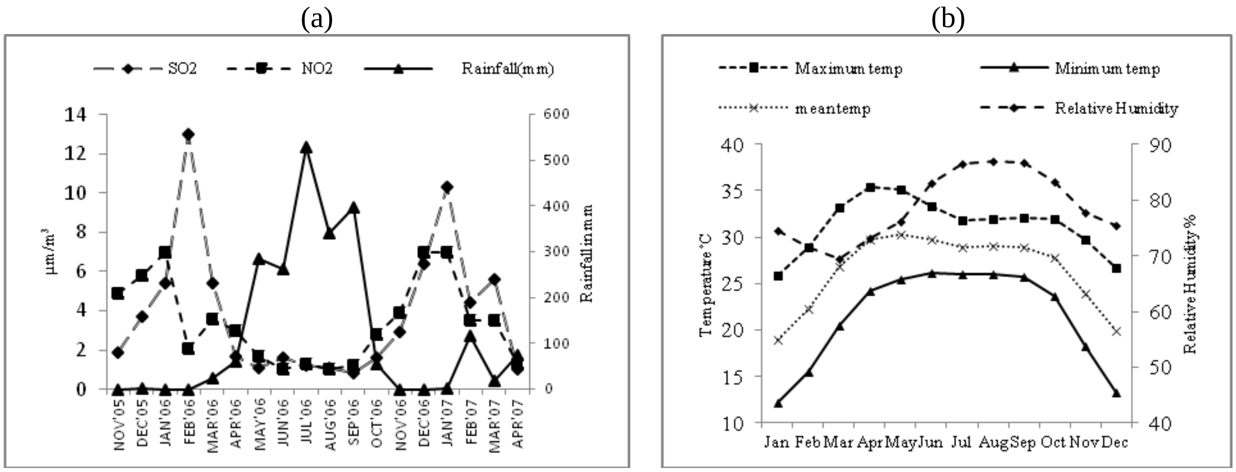

Figure 2. (a) Concentration of SO_2 and NO_2 and monthly rainfall of Sathkhira station during the study time (b) Monthly average maximum, minimum and mean temperature and monthly average relative humidity of the Sathkhira station.

The Figure 2a illustrates that the concentration of SOx and NOx has showed an inverse relationship with monthly rainfall. It appears that during dry season (November to March) the pollutant exhibit a higher concentration than the wet season. These relationships also supported by Pearson correlation test. The values of correlation coefficient in relation to rainfall to SOx and NOx were –0.541 and –0.689 respectively (Table 2). Both relationships were statistically significant at 95 percent and 99 percent confidence limit respectively. Higher concentration of SOx and NOx is observed in the case of lower humidity and temperature (Figure 2b). It is also evident from Figure 2a and 2b that there is a seasonal variability of pollutants concentration in Sathkhira monitoring station. In the dry season (November to March) the pollutant concentration remains higher in comparison to the wet season. The Pearson correlation among average monthly temperature and concentration of SOx and NOx showed a negative correlation (r= –0.601 for SOx and r=–0.920 for NOx) with 99 percent confidence limit (Table 2).

Table 2. Pearson correlation among SOx, NOx, rainfall and average temperature

	SOx	NOx	Rainfall	Avg Temp
SOx	1			
NOx	0.483*	1		
Rainfall	–0.541*	–0.689**	1	
Avg Temp	–0.601**	–0.920**	0.612**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

3.2 Back Ward Trajectory Analysis

Transboundary transport when present for a few days is related to some typical synoptic situations [29]. In the present study backward trajectories are calculated from December, 2005 to March 2007 at five days interval. Eighty five trajectories calculated are broadly classified into two categories on the basis of travel path and or wind direction. Transport of air masses over west Bengal are further divided into six categories wherever transport of air masses over the Bay of Bengal are divided into five categories.

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3.2.1 Transport of Air Masses over West Bengal

The travel of the air masses from the west Bengal of India has been observed in 8 months among the 14 months study period. These months are mainly in winter seasons from December to March. Figure 3 is a representative of air masses that are travelling over West Bengal of India. This figure showed the different source of origin of the air masses but all of them are travelled through almost a same path.

The trajectory of December, 2005 showed (Figure 3a) that the source of the air masses is in Himachal Pradesh of India and after travelling through Uttar Pradesh, Bihar and West Bengal it reached at Sathkhira. Figure 3b indicates that the source point of air masses in 31 January 2006 is from Peshawar of Pakistan. After originating from its source the trajectories remain almost similar as that of in 5 December 2005. In 5 February 2006 the source point of the pollutant is observed in Rajasthan (South west). Due to the north and north-west flow of wind, starting from Rajshtan trajectory found to move towards the Himachal Pradesh and after that turning to east travelled over Uttar Pradesh, Bihar and West Bengal before reaching Bangladesh (Figure 3c). The travel path of air masses on 20 March 2006 observed that after originating from the Kabul of Afganistan it has been travelled over Uttar Pradesh, Bihar and West Bengal before reaching to Sathkhira (Figure 3d).

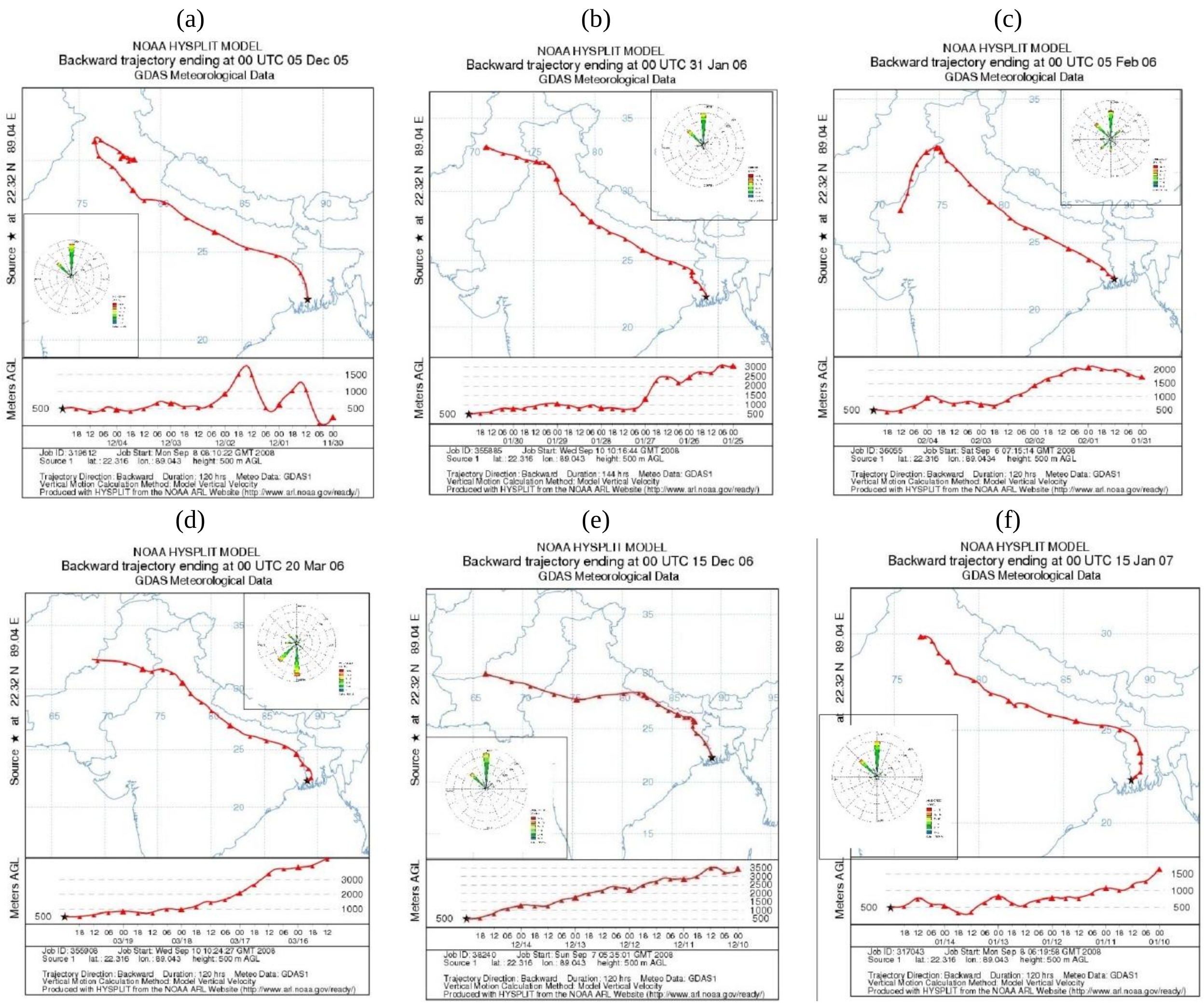

Figure 3. Representative 5-days backward trajectories and level of pollutant on that particular day at arrival point.

From Figure 3e it is evident that the air masses originating from Baluchistan of Pakistan move towards Madhya Pradesh of India and change its path to North-East. After that the trajectory has change it path ways by hindering to the Himalys to reach before Sathkhira. This trajectory also support the findings of Iqbal and Oanah [21] who stated that the pathways of air masses reflect the topography of the country with the long Himalayan range situated in the northern part of the Hilly region. In case of January 15, 2007 the back trajectory of air masses has showed that it entered in Bangladesh through the Rajshahi division before travel through west Bengal of India from its originating point of Uttar Pradesh (Figure 3f). The wind pattern of the study period suggests that the air masses arriving in the monitoring station are advected from North and North-West direction. During this period the atmospheric circulation over Bangladesh was dominated by cold-surface anticyclone. According to Kidnap [8] the trajectories associated with anticyclone are capable of transporting high concentration of pollutants over long distances. It also verifies the results showed in Figure 2a i.e. the concentrations of pollutant in these months are higher in comparison to any other months. Comrie [34] stated that air travelling below 3000 meters can gain pollution load from areas as it passes over. And it is also observed that some coal mine plants and thermal power plants are situated in the west Bengal of India which could be the source of these high concentration pollutants in the sathkhira monitoring station.
Sulphur content in emission differs depending on combustion conditions such as electricity generation or transporting this eventually leads to a difference in the ratio of SOx and NOx. Therefore it is possible to identify the source of pollution from the ratio of SOx and NOx [35]. Typically, electricity production is expected to result low SOx/NOx ratio than emissions caused by low-temperature boilers burning fuel oil with high sulfur content. It is found that the monthly averaged ratio of SOx to NOx in December to March 2005 and December to January 2007 was 0.64, 0.77, 6.19, 1.50, 0.91 and 1.47 respectively. Nirel and Dayan [35] categorized these ratios to identify the pollution sources into four categories. According to their index it could be concluded that in December 05, and January 06 the pollution source is mainly from the power plant and the day time emission of local industry. But in case of February 06, the ratio is observed to be very high that might be from the emission of large industry associated with high wind speed. Wind speed data of this month also associated with these predictions. The Wind speed in February 06 was 49.85% calm which was lower in comparison to the other months that travel pollutant over West Bengal of India (Figure 3).

3.2.2 Transport of Air Masses over Bay of Bengal

From the analysis of backward trajectories it is observed that the air masses transported to the Sathkhira monitoring station over Bay of Bengal during the months of April, May, June, July, September of 2006 and April of 2007 (Figure 4). The representative trajectory of 25 April 2006 and 2007 has exposed that the source points of pollutant is observed in Urissa and Andhra Pradesh of India (Figure 4a), but in the month of May and June the originating point of air masses are monitored at Jafna of Srilanka (Figure 4b) and middle east (Figure 4c) respectively. In case of July the basis of the air masses are also from Middle East. The representative wind direction during these months is observed mostly from south. So the direction of wind showed a similar pattern with trajectories. Figure 4e stand for the back trajectories of October, 2006. The trajectory has showed the traveling route of the pollutants and are mostly from north (Assam of India) and originating in China. After traveling over Bhutan, Nepal, it reaches at Satkhira. During this period wind mostly blew from north north-east and even from north-west. Similar pattern of northerly wind direction were also visible during the month of December 2006 when the source point of trajectories have been observed mainly from China.
The months when the trajectories travel over Bay of Bengal it is observed that concentration of NOx was higher than the concentration of SOx. World Health Organization (WHO) [7] explained that the main reason of NOx pollution is the combustion of fuel in vehicle. It is also agreed with our findings that a lot of ship ply in the Bay of Bengal emit a huge amount of pollutant in the atmosphere. Another reason of lower concentration of SOx may be the monsoon wind that blow over Bangladesh during these months to carry a huge amount of water droplets and the pollutants mixed with the water droplets and some parts

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precipitate to the land and it is may be one of the reasons for fewer amounts of pollutants in the atmosphere of Satkhira district.

Ohara *et al.*, [36] studied that China is the source of around 65% of the emitted SO2 of Asia and India is next to China which emit 14%. In addition they also found that around 65% (27.3 MT) of the emitted Asian NOx in the year 2000 was from China and the next emitter in the same year was India 17% (4.7 MT). These data also evaluate the presence of high concentration of SOx and NOx in Sathkhira monitoring station.

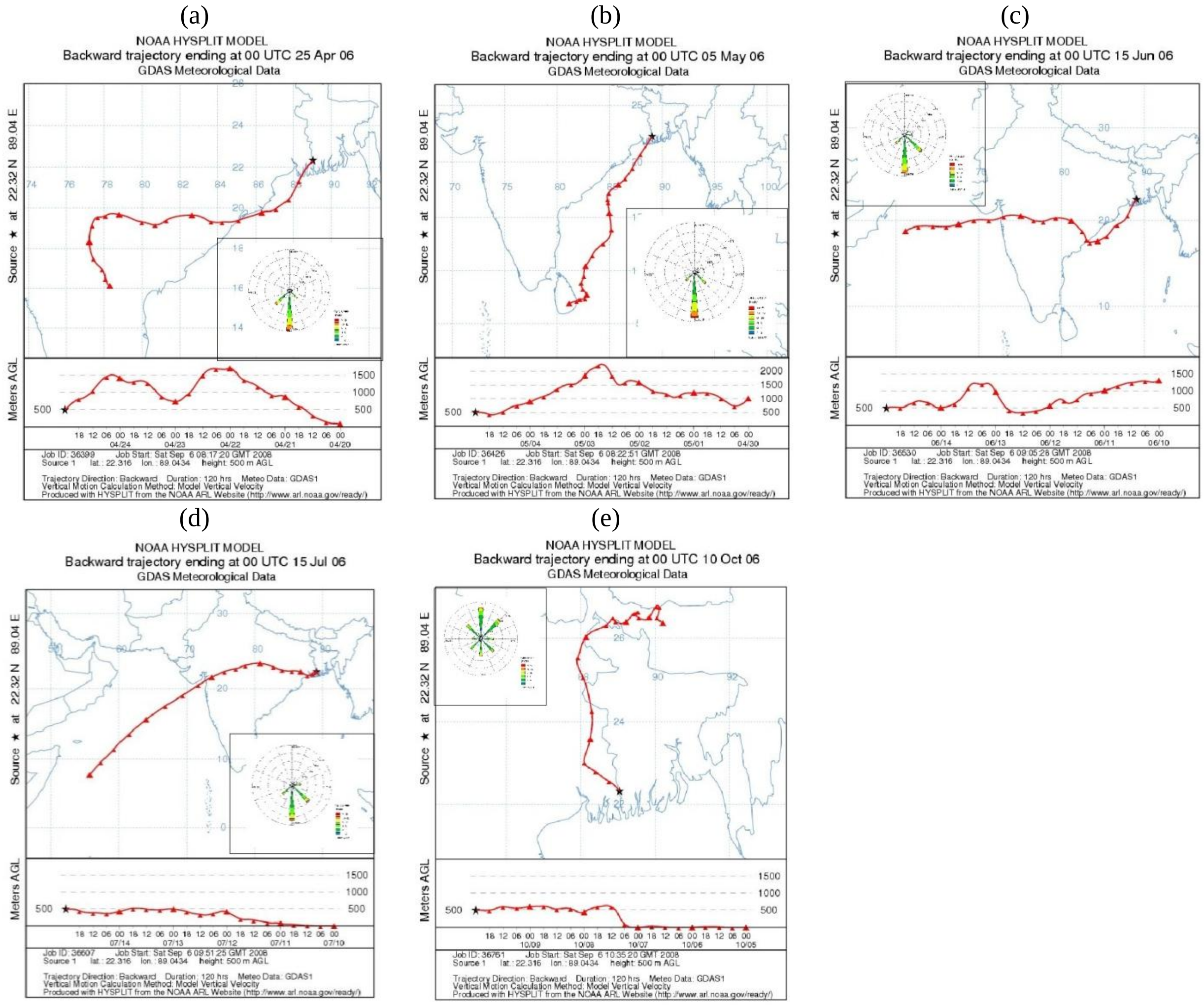

Figure 4. Representative 5-days backward trajectories and Level of pollutant on that particular day at arrival point.

4. CONCLUSION

Trajectory of transboundary air pollutants is studied in Satkhira station, Bangladesh. Wind data analyses showed that wind flows mostly from north and northwest in the dry season and from south, southwest and southeast but mainly from south in the rainy season. Trajectory analysis of atmospheric air pollutants found to be consistent with wind speed direction. The pollutants data renders that seasonal wind directions play a significant role in seasonal pollutants concentration level. A significant amount of air pollutants travel from beyond the boundary of Bangladesh due industrial activities in neighboring India and China, although it is not at alarming level yet. Precautionary initiative at bilateral and multilateral level might be found helpful to keep the level of air quality within permissible limit.

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