

## **TRAJECTORY ANALYSIS OF AIR POLLUTANTS FROM FEBRUARY 2020 TO JANUARY 2022 AT A UNIVERSITY CAMPUS**

**Shanjida Haque Dola\*, Jobaer Ahmed Saju\*\*, Md. Emdadul Haque\*\*\*, Joy  
Podder\*, S. Setu\*\*\*\*, Md. Abul Kalam Azad\*, N. J. Shila\*, Md. Nuhu Alam\* and  
Bidyut Datta\*\*\***

*\*European University of Bangladesh, Dhaka*

*\*\*Khulna University of Engineering & Technology, Khulna*

*\*\*\*International University of Business Agriculture and Technology, Dhaka*

*\*\*\*\*Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh*

### **ABSTRACT**

Air pollution is a great concern in urban areas of Bangladesh because of the emissions from various anthropogenic sources. Identification of sources of respective air pollutants is needed to control the affluence of pollution. This study aimed to ascertain the possible sources which are polluting the air surrounding the European University of Bangladesh, Dhaka. This study investigated the long-range transport of air pollutants at the selected location of Dhaka city. The trajectory paths were investigated and the transboundary sources of air pollutants were identified at intervals of every five days for two years: February 2020 to January 2022. In the season of pre-monsoon, backward trajectory paths generally came through Kolkata, India; Bay of Bengal; Bengaluru, India. In the monsoon season of 2021, backward trajectory paths were mostly generated from the Bay of Bengal; the Arabian Sea, and some other places in India. In the post-monsoon season, backward trajectory paths traveled through some places of India but mostly it was the Bay of Bengal. In the winter season of 2021 and 2022, backward trajectory paths followed the west- Bengal route to reach the considered location. The backward trajectory analysis concluded that trajectories followed the west Bengal path and the Bay of Bengal path. The higher concentration of all air pollutants can be observed when the trajectories followed the west Bengal path, indicating the contribution of industrial activities in neighboring India, China, and Bhutan to the concentrations of air pollutants behind the perimeter of Bangladesh. This study will contribute to understanding the possible sources of air pollutants polluting the air around the considered location.

**Key words:** Air pollution, HYSPLIT, Particulate matter; Wind Direction; Transboundary pollution.

### **INTRODUCTION**

Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities, and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. Outdoor and indoor air pollution causes respiratory and other diseases and is an important source of morbidity and mortality.

Air pollution is one of the major manmade environmental problems that had recently gained importance among environmental issues in Bangladesh (Ahmed & Hossain, 2008). Bangladesh has been ranked fourth among 91 countries with the worst urban air quality in the latest air pollution monitoring report of the World Health Organization (WHO, 2014). Moreover, three Bangladeshi cities such as Narayanganj, Dhaka, and Gazipur have been among the top 25 cities with the poorest air. The 2014 version of the Ambient Air Pollution (AAP) database consists mainly of urban air quality

data from 1600 cities from 91 countries. In the city-wise assessment, Narayanganj has been marked as the 17th city with the worst air quality whereas Gazipur and Dhaka have been ranked 21st and 23rd respectively (The Daily Star, 2014). According to the report, almost 90 percent of people living in the cities are being exposed to dangerous levels of air pollution. Outdoor air pollution killed 3.7 million people in 2012 and the WHO says it is now the world's largest single environmental health risk (WHO, 2014). The report also states only 12 percent of people are living in cities that conform to the WHO air quality guideline levels. The report was prepared based on the monthly air quality monitoring data of 2013 of the Department of Environment (DoE), Bangladesh. The DoE has set up air quality monitoring stations in eight (8) cities, including Dhaka, Narayanganj, Gazipur, Rajshahi, Chittagong, Khulna and Sylhet. Though Narayanganj has the highest level of gaseous pollutants, the report shows the air of the northern metropolis Rajshahi contains the highest level of dust particles (The Daily Star, 2014). Among the gaseous pollutants which the DoE measures are carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>) and ozone (O<sub>3</sub>), methane and non-methane pollutants.

At present, air pollution from the power generation sector is under investigation as the prevalence of different fuel options such as natural gas, coal, and HFO. Numerous diesel generators currently supplement the infrequent grid electricity supply in the residential, industrial, and commercial sectors. These diesel generators currently pose risk to the surrounding environment. Like other developing countries, up to 10% of respiratory infections and diseases in Bangladesh can be attributable to urban air pollution (World Bank, 2006). Heavy toxic trace metals carried by atmospheric particles can change the chemical composition of metals after settling on the superficial soil, thus changing their bioavailability in the soil and water (Hernandez et al., 2003). Particularly, industrial and automotive emissions contribute to a larger extent in this respect (Kakulu, 2003). The air quality index (AQI) is a tool for reporting the daily air quality of any city or country. It provides information about how clean or polluted the air is, and what associated health effects might be a concern for the public. The AQI focuses on the health effects that one might experience within a few hours or days after breathing polluted air. The AQI value is a yardstick that runs from 0 to 300. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI of 50 represents good air quality with little potential to affect public health, while an AQI value of 300 represents hazardous air quality. An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level that set by the mandated Environment Protection Agency (e.g., for Bangladesh Department of Environment) to protect public health. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy—at first for certain sensitive groups of people, then for everyone as AQI values get higher. The main purpose of the air quality index is to Daily release air quality conditions to the public, convey the health implications of air quality, protect the public interest and take actions to reduce emissions and forecast air pollution levels. In Bangladesh, the AQI is based on 5 criteria pollutants; Particulate Matter (PM<sub>10</sub> and PM<sub>2.5</sub>), NO<sub>2</sub>, CO, SO<sub>2</sub> and Ozone (O<sub>3</sub>). The Department of Environment (DoE) has also set national ambient air quality standards for these pollutants.

There have been various review papers on atmospheric modeling and their approaches to the dispersion of pollutants (Vardoulakis et al., 2003) and comparisons between different models using meteorological data (Ellis et al., 2001). Unfortunately, only a few studies have simultaneously measured particle concentration with gases and the differences between the studies may be partially responsible for the differences observed. In open sites, several studies have shown varying correlations between the concentrations of gases and particles. (Monn et al., 1997) showed a poor correlation between the outdoor PM<sub>10</sub> concentrations and NO<sub>2</sub> concentrations in an urban environment with a better correlation between PM<sub>2.5</sub> and NO<sub>2</sub>. (Roorda-Knape et al., 1998) observed that benzene, PM<sub>10</sub> and PM<sub>2.5</sub> showed no significant decrease in concentration up to 300m from a major motorway. This was consistent with the small decrease in the PM<sub>10</sub> and PM<sub>2.5</sub> concentration observed by (Hitchins et al., 2000). In that study, the authors observed that particle number concentration decreased faster than NO<sub>2</sub> concentration from a motorway. (Zhu et al., 2002) showed that the number concentration of particles between 6 and 220nm correlated well with CO concentration from a motorway. All of these studies were made in an open environment where the wind direction was perpendicularly away from the road. However, differences have been observed between the local dispersion of gases and particles (Holmes et al., 2005; Morawska, 2003). Simultaneous measurements of CO and particle number concentration showed that CO concentration was not significantly correlated to particle number concentration around the site and examination of between-site comparisons with the two pollutants showed different spatial and temporal trends. In another study of urban sites (Harrison & Jones, 2005) observed that particle concentrations correlated only weakly with NO<sub>x</sub>, with the highest correlation observed at a curbside monitoring location, where concentrations are less affected by dispersion. In addition, an examination of many urban studies

(Morawska, 2003) has shown that the vertical profiles of particle number concentration around buildings differed from that of gases. These studies differ from the previous studies in that they were conducted in a more complex environment where wind flows were heavily affected by turbulence and emissions were not limited to a single line source. HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model developed jointly by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) and the Australian Bureau of Meteorology, is a computational tool designed to produce air parcel trajectories, and to carry out simulations on different spatial and time scales from local, regional and long-range transport, dispersion, and deposition of air pollutants (Stein et al., 2015). (Draxler, 2006) used the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to predict the transport and dispersion of trace plumes over Washington, DC. (Myles et al., 2009) reported that sulfur and nitrogen oxides react in the atmosphere to form compounds that may be transported over long distances using HYSPLIT dispersion modeling. (Challa et al., 2009) showed the mesoscale transport and dispersion of air pollutants in the Mississippi Gulf coastal region using HYSPLIT dispersion modeling.

Back-trajectory calculations have been one of the most attractive and prominent features by which HYSPLIT has been used in many studies (Fleming et al., 2012). Although trajectories offer a simple assessment of source–receptor relationships, a single trajectory cannot adequately represent the turbulent mixing processes that air parcels experience during transport. However, coupling the back-trajectory calculation with a Lagrangian dispersion component can produce a more realistic depiction of the link between the concentrations at the receptor and the sources influencing it (Lin et al., 2003). Under this approach, the increasingly wider distribution of Lagrangian particles or puffs released from a receptor undergoing backward in time transport and dispersion represents the geographical extent and strength of potential sources influencing the location of interest. Nevertheless, this particular model application must satisfy the well-mixed criteria and include an appropriate representation of the interaction between the wind shear and vertical turbulence (Lin et al., 2003). (Hernandez-Ceballos et al., 2014) used HYSPLIT trajectory model to detect the source areas and calculate transport dynamics for airborne olive pollen observed in the city of Cordoba, southwest of the Iberian Peninsula, (Bella et al., n.d.) characterized the pollution transport into Texas using HYSPLIT back trajectory model. HYSPLIT's minimum time step is 1 minute, so the model cannot be used for transport less than the distance it takes for the pollutant to move in 1 minute. However, keep in mind that the meteorology may not adequately represent the transport/dispersion at the point of release regardless of the model time step. For scales, less than 1 km the CAMEO/ALOHA model is recommended.

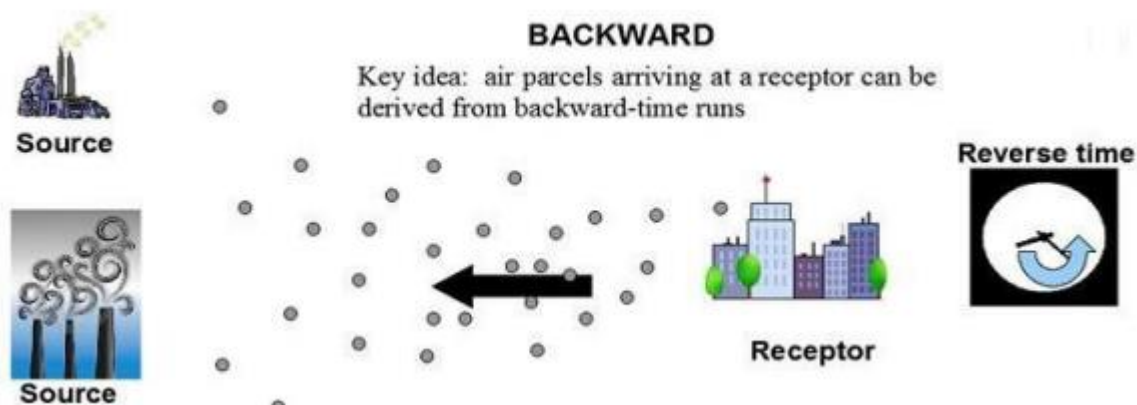


Figure 1 Backward-time stochastic Lagrangian particle simulated to describe atmospheric transport (Fleming et al., 2012)

Meteorological data used to force HYSPLIT is available at a relatively coarse temporal resolution (1-6 hours), which can result in errors in rapidly changing conditions, even if the NWP model itself can faithfully emulate these conditions. NWP models also have limitations in their ability to accurately forecast the onset and spatial scales of phenomena that may affect dispersion, such as sea breezes and mountain-valley circulations. The meteorological data used by HYSPLIT is bi-linearly interpolated in space and linearly interpolated in time to the location and time of a pollutant release and during the forecast of the subsequent diffusion of materials. If important variations in the meteorological fields occur between grid points or between meteorological data output times, concentration errors may result.

Air pollution has a major impact on the process of plant evolution by preventing photosynthesis in many cases, with serious consequences for the purification of the air we breathe. It also contributes to the formation of acid rain, atmospheric precipitations in the form of rain, frost, snow or fog, which are released during the combustion of fossil fuels and transformed by contact with water steam in the atmosphere. On top of that, air pollution is a major contributor to global warming and climate change. The abundance of carbon dioxide in the air is one of the causes of the greenhouse effect. Normally, the presence of greenhouse gases should be beneficial for the planet because they absorb the infrared radiation produced by the surface of the earth. But the excessive concentration of these gases in the atmosphere is the cause of the recent climate change. Our continual exposure to air pollutants is responsible for the deterioration of human health. Air pollution is indeed a significant risk factor for human health conditions, causing allergies, respiratory and cardiovascular diseases as well as lung damage. Therefore, ascertainment of air pollution sources is indeed a crucial task for a considering location. This study aimed to identify the potential transboundary sources which are mostly liable to pollute the air surrounding the European University of Bangladesh for consecutive two years.

## RESEARCH METHODS

Backward trajectories were determined using the NOAA HYSPLIT model in order to examine the long-range transport of contaminants. For the endpoints of each section describing each particular time interval being modeled, the trajectories are described as a sequence of latitude and longitude values. In this model, the vertical motion of air parcels is considered. In the region of Dhaka city, archived meteorological information was used to research long range transport particles. By using HYSPLIT-4, the theory of drawing backward trajectories is based on the integration of the air mass location with respect to time. Using the wind, the air mass is transported, its passive transport can be measured by evaluating the three-dimensional means of velocity vector when the particles are in the primary position  $P(t)$  and the first estimated position  $P'(t + dt)$ . Backward trajectory analysis is well known to investigate the long-range transport of air pollutants. In this study, backward trajectories were in all monitoring locations of EUB, Dhaka from February 2020 to January 2022. A total of 72 trajectories have been calculated in one year. The important input parameters are presented in table 1.

Table 1 Important input parameters in the HYSPLIT model

Description	Input Parameter
Trajectory direction	Backward
Motion Model	vertical velocity
Total run time (hours)	120
Start a new trajectory every	0
Maximum number of trajectories	1
Zoom factor	70
Plot resolution (dpi)	96
Vertical plot height (meters)	500

Trajectories were calculated considering 500 meters heights. Therefore, a total of 72 trajectories in one year showed 144 trajectory paths through which the pollutants were transported to particular locations. In this study, the validation of the HYSPLIT meteorological data file was conducted by creating a wind rose diagram from regional air quality data and another from HYSPLIT. Wind rose diagrams incorporating nearly the same direction of trajectory paths reflects validated HYSPLIT meteorological data file.

## RESULTS AND DISCUSSION

Dhaka witnessed a seven percent rise in air pollution in 2021 compared to the last five years, according to recent studies incorporating considerable seasonal variation. As per the season, there could be some different and similar backward trajectory path at the selected location: European

University of Bangladesh, Dhaka (23.784228040481842 N, 90.34531095506586 E). The trajectory path analysis was performed considering four seasons which are given below.

- Pre-monsoon: March, April, May;
- Monsoon: June, July, August, September;
- Post-monsoon: October, November;
- Winter: December, January, February.

### Backward trajectory analysis of the winter season

The trajectory path on 5<sup>th</sup> February 2020 traveled to the considered location through Nagpur-Indore-Gaya-West Bengal-Chapai Nawabganj-Natore-Faridpur-Savar. In the same way, the trajectory path of 5<sup>th</sup> February reached EUB, Dhaka by following the path “Meghalaya-Sheerpur-Tangail EUB, Dhaka” The depicted backward trajectory paths are exhibited in Figure 2.

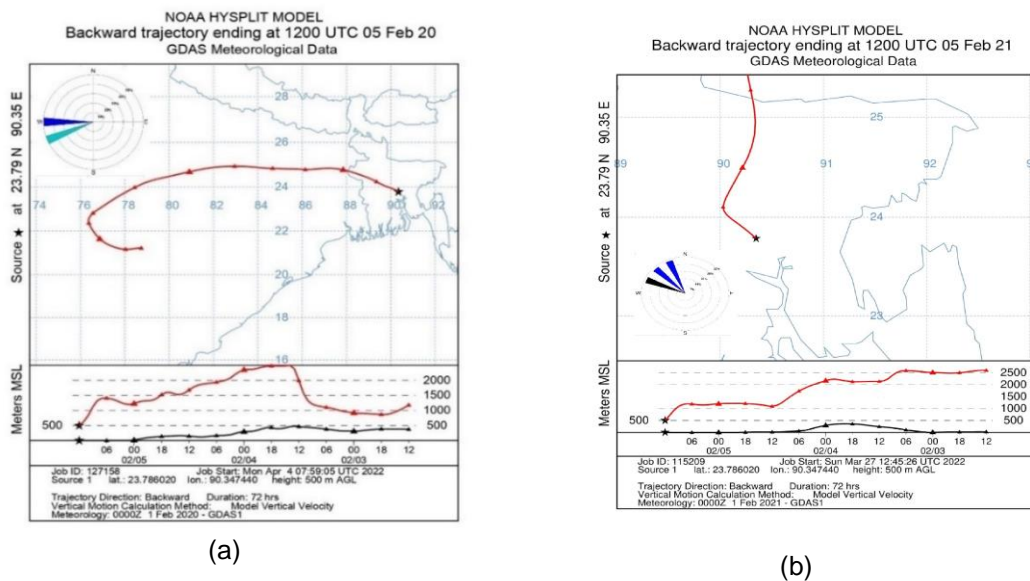


Figure 2 Backward trajectory of winter season (a) February 2020, (b) February 2021

Trajectory path for the study location originated from Indore and traveled through Lakhimpur-Janakpur-Joypurhat-Bogura-Serajonj-Tangail to EUB Dhaka. This trajectory was generated on 5<sup>th</sup> January 2021 as displayed in Figure 3. “Bashipura-Bongaigaon-Kurigram-Sirajganj-Tangail-EUB, Dhaka” path was followed by the trajectory calculated on 5<sup>th</sup> January 2022.

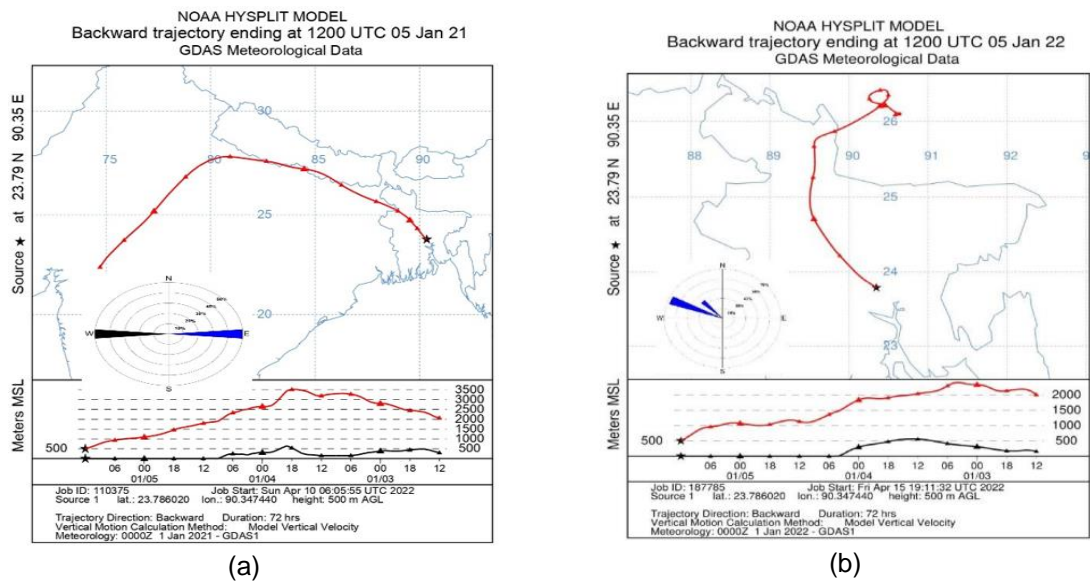


Figure 3 Backward trajectory of winter season (a) January 2021, (b) January 2022

Trajectory paths for dates 5<sup>th</sup> December 2020 and 5<sup>th</sup> December 2021 at the location “EUB” are presented in Figure 4. Monitoring campaign for this location was in the month of 5<sup>th</sup> December 2020. 500 m height Trajectory on 5<sup>th</sup> December 2020 was found to start from Jaunpur. Afterward, traveled through the path “Gaya-West Bengal-Rajshahi-Veramara-Pabna-Rajbari-Manikgonj to EUB Dhaka”. However, “Bashipura-Bongaigaon-Kurigram-Sirajganj-Tangail- EUB, Dhaka” was followed by the trajectory generated on 5<sup>th</sup> December 2021.

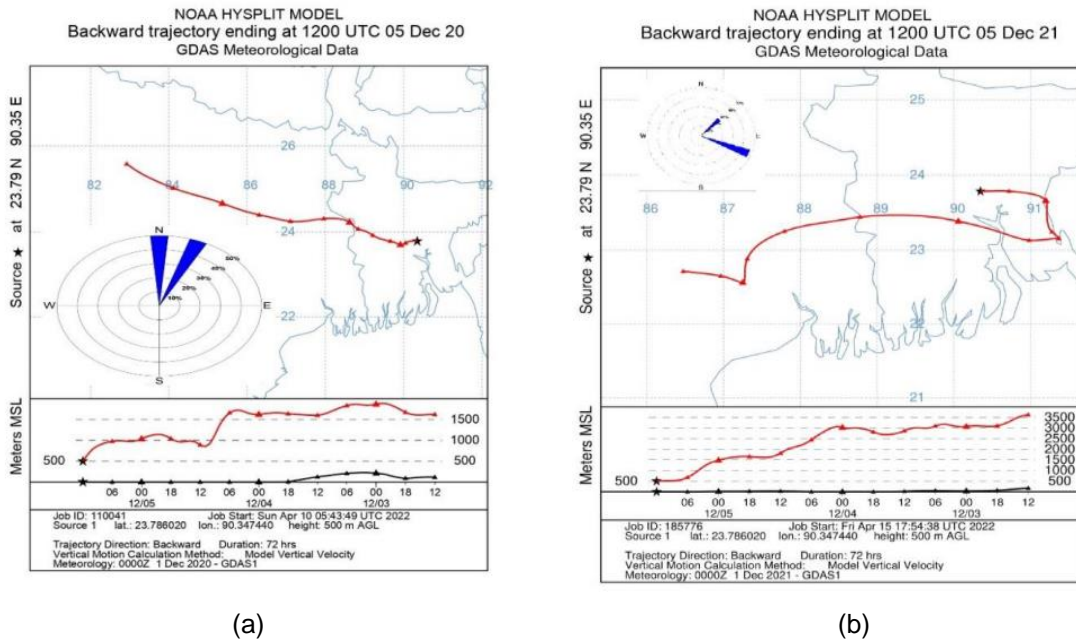
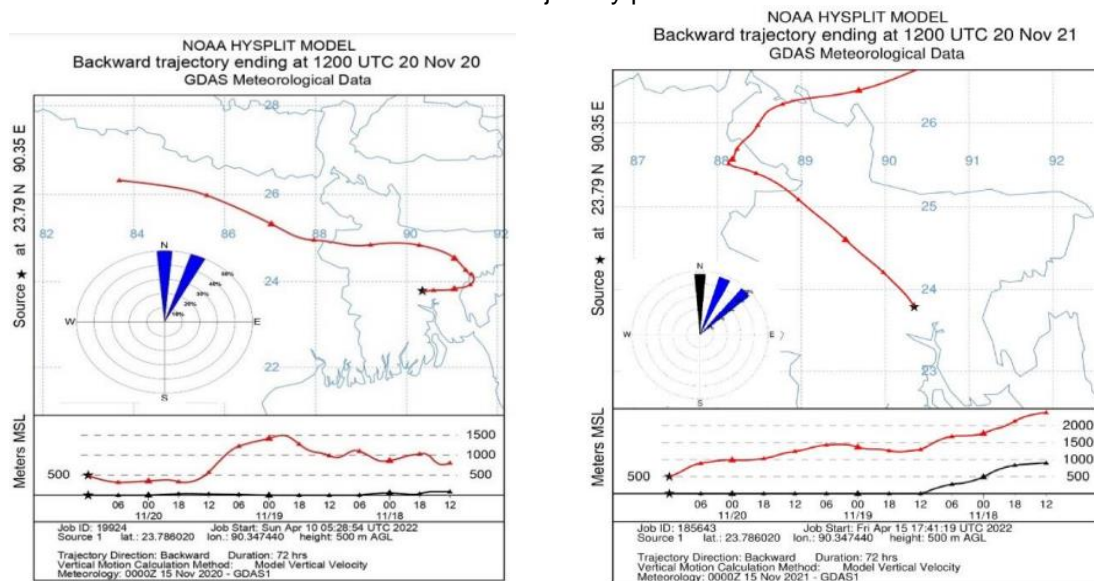


Figure 4 Backward trajectory of winter season (a) December 2020, (b) December 2021

**Backward trajectory analysis of the post-monsoon season**

Trajectory paths arrived at the study location by following the paths “Deoria-Bhagalpur-Noagon-Bogura-Mymensing-Hobigonj-B.baria to EUB, Dhaka” and “Manas Tiger Reserve-Kuchbihar – Thakurgaon – Joypurhat – Tangail – EUB, Dhaka”. The backward trajectories were generated at the dates 20<sup>th</sup> November 2020 and 20<sup>th</sup> November 2021 can be observed in Figure 5. The figures showed similar direction of wind and backward trajectory paths.

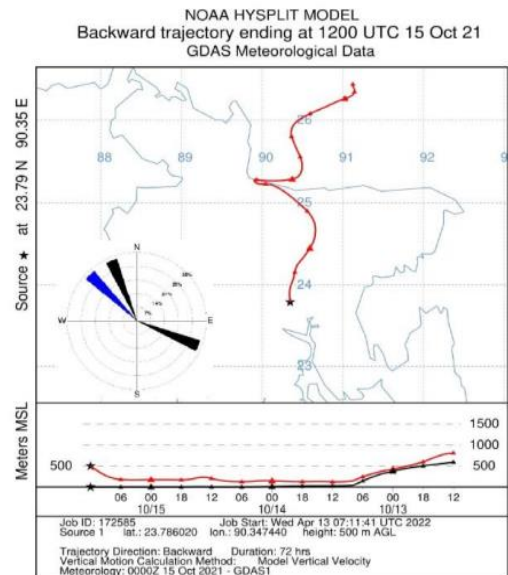
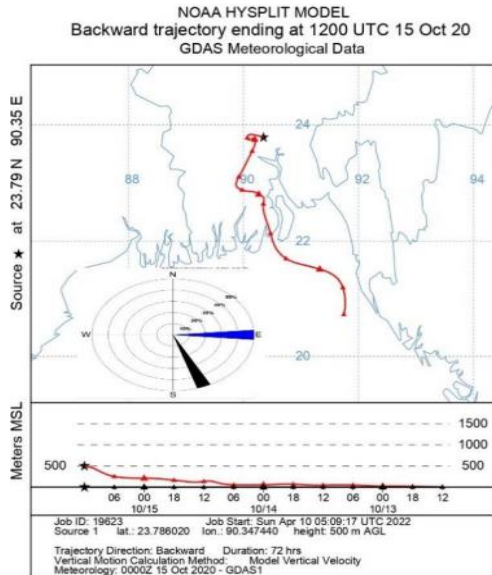


(a)

(b)

Figure 5 Backward Trajectory of post-monsoon season (a) November 2020, (b) November 2021

Trajectory paths at the study location originated from Indian Ocean and Barpeta on the dates 15<sup>th</sup> October 2020 and 15<sup>th</sup> October 2021. Figure 6 (a) showed the path for 15<sup>th</sup> October 2020 as “Indian Ocean -Patuakali-Barisal-Golapgonj-Nobabgonj-Singail-Savar to EUB Dhaka” and Figure 6 (b) displayed the path as “Barpeta-Goalpara-Mawspong-Sherpur-Kishorganj- EUB, Dhaka” for 15<sup>th</sup> October 2021.



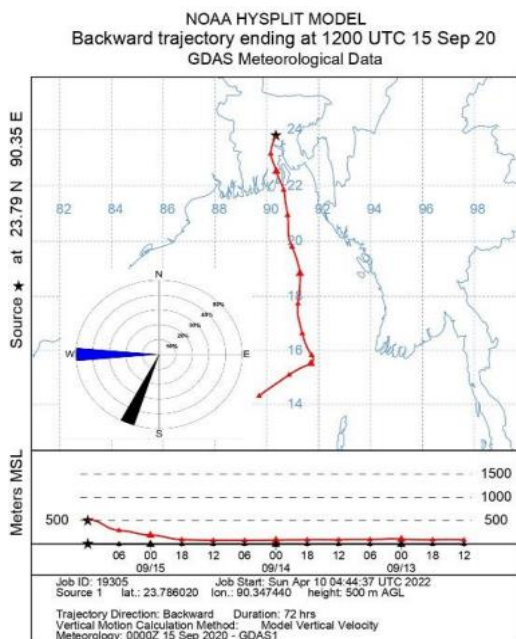
(a)

(b)

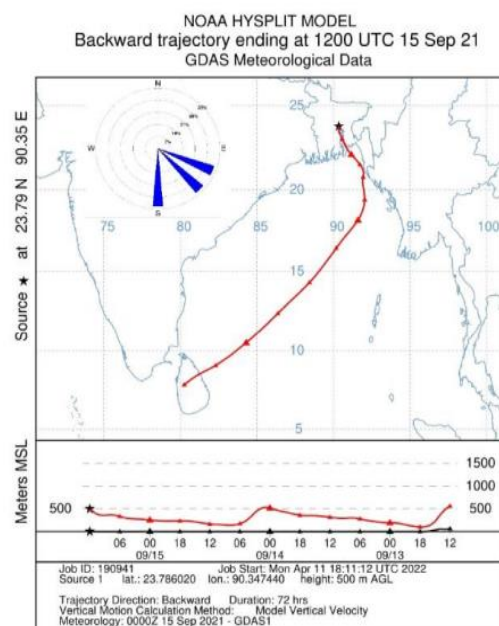
Figure 6 Backward Trajectory of post-monsoon season (a) October 2020, (b) October 2021

### Backward trajectory analysis of monsoon season

Trajectory paths generated for monsoon season illustrated in Figure 7 and Figure 8. “Indian Ocean-Bay of Bengal-Bhola-Barisal-Madaripur-Mowa to EUB Dhaka” path was followed by the trajectory generated for 15<sup>th</sup> September 2020 and “Maho-Bay of Bengal-Cox’s Bazar-Chandpur-Narayanganj- EUB Dhaka” was traced for 15<sup>th</sup> September 2021.



(a)



(b)

Figure 7 Backward Trajectory of monsoon season (a) September 2020, (b) September 2021

Trajectory paths for 15<sup>th</sup> July 2020 and 15 July 2021 at the study location found to be originated from Maratankadawla and Bay of Bengal as displayed in Figure 8. Trajectory path for 15<sup>th</sup> July 2020 traveled through “Maratankadawla-Bay of Bengal-BholaNoria-Shirajdikhan-Keranigonjto EUB Dhaka”. Accordingly, Trajectory paths for 15<sup>th</sup> July 2021 followed the path “Bay of Bengal-Bhola-Barishal-Madripur- EUB Dhaka”

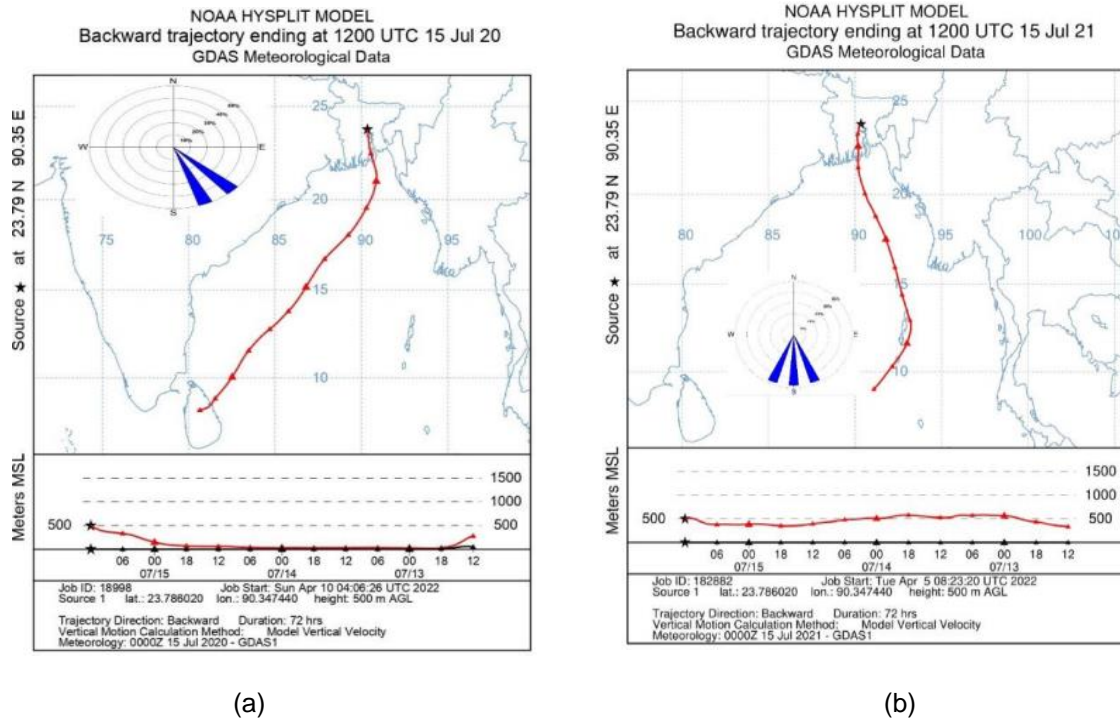


Figure 8 Backward Trajectory of monsoon Season (a) July 2020, (b) July 2021

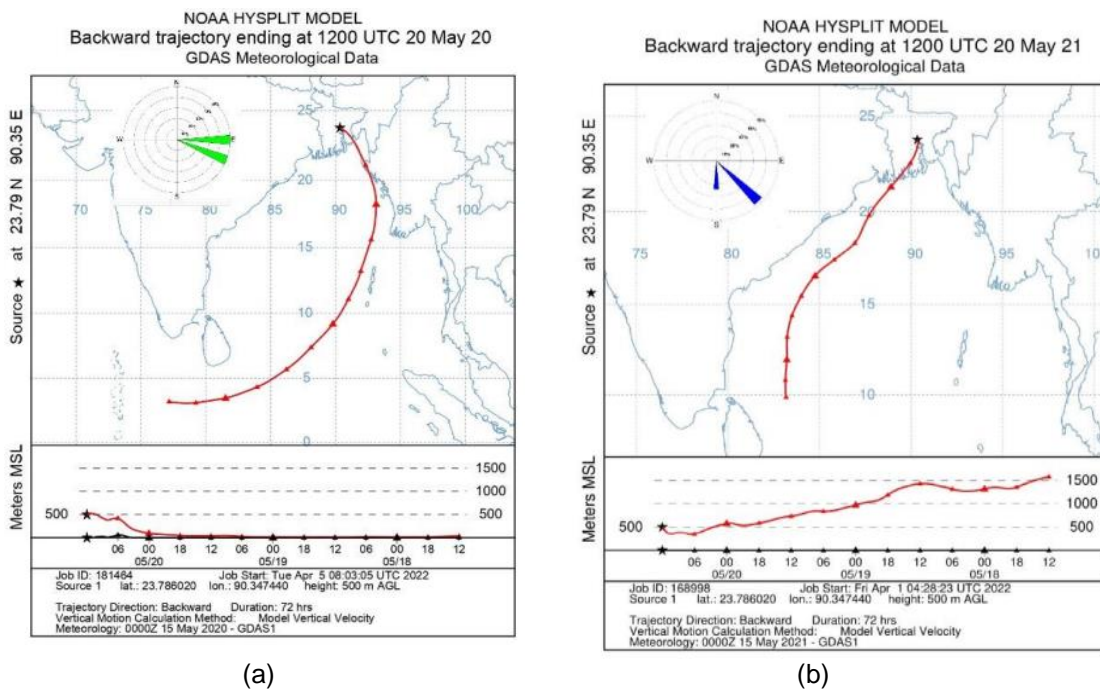


Figure 09 Backward Trajectory of pre-monsoon Season (a) May 2020, (b) May 2021

### Backward trajectory analysis of pre-monsoon season

Trajectory paths for the pre-monsoon season are shown in Figure 9 and Figure 10. “Bengal-Cox’s Bazar-Chottogram-Noakali-Kumilla-Narayangonj to EUB Dhaka” was the path for the trajectory generated on 20 May 2020 as displayed in Figure 9 (a). The trajectory path of 20 May 2021 followed the path “Bay of Bengal-Shundarbans-Barishal- EUB Dhaka” as illustrated in Figure 9 (b). “Bay of Bengal-Potua-kali-Noakhali-Chandpur-Narayangonj-to EUB Dhaka” was the path followed by the trajectory generated on 20<sup>th</sup> April 2020 shown in Figure 10 (a). Accordingly, the trajectory of 20<sup>th</sup> April 2021 displayed in Figure 10 (b) originated from Pakistan and followed the path “Pakistan-Delhi-Lucknow-Kolkata-Jashore-Savar- EUB Dhaka”.

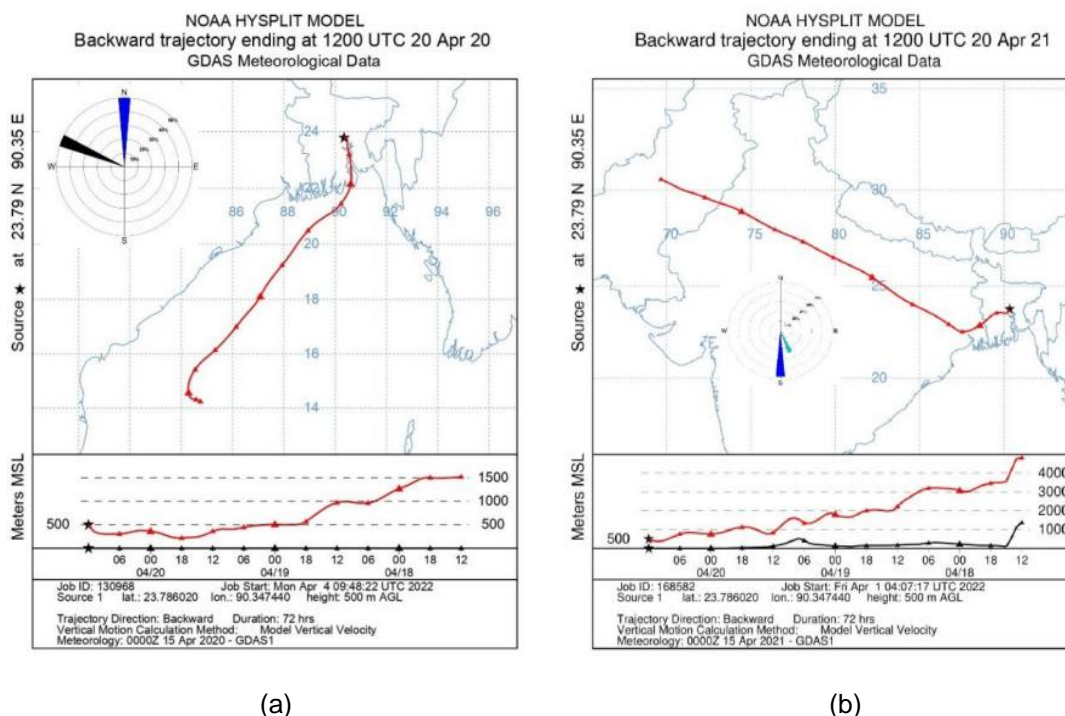


Figure 10 Backward Trajectory of pre-monsoon Season (a) April 2020, (b) April 2021

### CONCLUSIONS

Backward trajectory analysis is well known to investigate the long-range transport of air pollutants. In this study, backward trajectories were generated for the location EUB, Dhaka (23.784228040481842 N, 90.34531095506586 E) from February 2020 to January 2022. Total of 144 backward trajectories was calculated for two years at 5 days interval. The results are displayed according to the chronology of designated seasons of Bangladesh. The trajectory paths were investigated and the transboundary sources of air pollutants were identified for two years. The specific outcomes of this study are as follows:

- In the season of pre-monsoon 2021, backward trajectory paths generally came through Kolkata, India; Bay of Bengal; Bengaluru, India.
- In the monsoon season of 2021, backward trajectory paths were mostly generated from the Bay of Bengal; the Arabian Sea and some other places in India.
- In the season of post-monsoon 2021, backward trajectories traveled through some places of India but mostly it was the Bay of Bengal.
- In the season of winter 2021 and 2022, backward trajectory paths followed the west Bengal route to reach the considered location.

## REFERENCES

- Ahmed, S., & Hossain, I. (2008). Applicability of Air pollution Modeling in a Cluster of Brickfields in Bangladesh. *Chemical Engineering Research Bulletin*.
- Bella, D., Culpepper, J., Khaimova, J., Ahmed, N., Belkalai, A., Arroyo, I., Andrews, J., Gentle, S., Emmanuel, S., & Lahmouh, M. (n.d.). Characterization of pollution transport into Texas using OMI and TES satellite, GIS and in situ data, and HYSPLIT back trajectory analyses: implications for TCEQ State Implementation Plans. *Air Quality, Atmosphere & Health*.
- Challa, V. S., Indracanti, J., Rabarison, M. K., Patrick, C., Baham, J. M., Young, J., Hughes, R., Hardy, M. G., Swanier, S. J., & Yerramilli, A. (2009). A simulation study of mesoscale coastal circulations in Mississippi Gulf coast. *Atmospheric Research*, 91(1), 9–25.
- Draxler, R. R. (2006). The use of global and mesoscale meteorological model data to predict the transport and dispersion of tracer plumes over Washington, DC. *Weather and Forecasting*, 21(3), 383–394.
- Ellis, K., McHugh, C., Carruthers, D., & Stidworthy, A. (2001). Comparison of ADMS-Roads, CALINE4 and UK DMRB Model Predictions for Roads. 7th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. *Belgirate, Italy*.
- Fleming, Z. L., Monks, P. S., & Manning, A. J. (2012). Untangling the influence of air-mass history in interpreting observed atmospheric composition. *Atmospheric Research*, 104, 1–39.
- Harrison, R. M., & Jones, A. M. (2005). Multisite study of particle number concentrations in urban air. *Environmental Science & Technology*.
- Hernandez-Ceballos, M. A., Soares, J., García-Mozo, H., Sofiev, M., Bolivar, J. P., & Galán, C. (2014). Analysis of atmospheric dispersion of olive pollen in southern Spain using SILAM and HYSPLIT models. *Aerobiologia*.
- Hernandez, L., Probst, A., Probst, J. L., & Ulrich, E. (2003). Heavy metal distribution in some French forest soils: evidence for atmospheric contamination. *Science of The Total Environment*.
- Hitchins, J., Morawska, L., Wolff, R., & Gilbert, D. (2000). Concentrations of submicrometre particles from vehicle emissions near a major road. *Atmospheric Environment*.
- Holmes, N. S., Morawska, L., Mengersen, K., & Jayaratne, E. R. (2005). Spatial distribution of submicrometre particles and CO in an urban microscale environment. *Atmospheric Environment*, 39(22), 3977–3988.
- Kakulu, S. E. (2003). Trace metal concentration in roadside surface soil and tree bark: A measurement of local atmospheric pollution in Abuja, Nigeria. *Environmental Monitoring and Assessment*.
- Lin, J. C., Gerbig, C., Wofsy, S. C., Andrews, A. E., Daube, B. C., Davis, K. J., & Grainger, C. A. (2003). A near-field tool for simulating the upstream influence of atmospheric observations: The Stochastic Time-Inverted Lagrangian Transport (STILT) model. *Journal of Geophysical Research: Atmospheres*, 108(D16).
- Monn, C. H., Fuchs, A., Högger, D., Junker, M., Kogelschatz, D., Roth, N., & Wanner, H.-U. (1997). Particulate matter less than 10  $\mu\text{m}$  (PM<sub>10</sub>) and fine particles less than 2.5  $\mu\text{m}$  (PM<sub>2.5</sub>): relationships between indoor, outdoor and personal concentrations. *Science of the Total Environment*, 208(1–2), 15–21.
- Morawska, L. (2003). Motor vehicle emissions as source of indoor particles. *Indoor Environment*, 17, 297–319.
- Myles, L., Dobosy, R. J., Meyers, T. P., & Pendergrass, W. R. (2009). Spatial variability of sulfur dioxide and sulfate over complex terrain in East Tennessee, USA. *Atmospheric Environment*, 43(18), 3024–3028.
- Roorda-Knappe, M. C., Janssen, N. A. H., De Hartog, J. J., Van Vliet, P. H. N., Harssema, H., & Brunekreef, B. (1998). Air pollution from traffic in city districts near major motorways. *Atmospheric Environment*.

- Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., & Ngan, F. (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system. *Bulletin of the American Meteorological Society*, 96(12), 2059–2077.
- The Daily Star. (2014). Bangladesh 4th most polluted in world. *The Daily Star*.
- Vardoulakis, S., Fisher, B. E. A., Pericleous, K., & Gonzalez-Flesca, N. (2003). Modelling air quality in street canyons: a review. *Atmospheric Environment*.
- WHO. (2014). *WHO's Ambient Air Pollution Database*. World Health Organization.
- World Bank. (2006). Country Environmental Analysis. *Bangladesh Development Series*.
- Zhu, Y., Hinds, W. C., Kim, S., & Sioutas, C. (2002). Concentration and size distribution of ultrafine particles near a major highway. *Journal of the Air & Waste Management Association*, 52(9), 1032–1042.