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Air Pollution Prediction Based on Changes in Monsoon Wind Direction by Using Trajectory-Geospatial Approach

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ABSTRACT

Industrial areas are typically associated with hazardous levels of air pollution to human health and the environment. The growing number of factories in the area poses an ever-greater threat to the surrounding communities. One of the several incidents pointing to poor air quality in the industrial region is the severe air pollution incident that occurred in Pasir Gudang in June 2019 which brought adverse health impacts to nearby schoolchildren. This study intended to ascertain the role of meteorological factors and impacts on the dispersion of air pollution in the Pasir Gudang Industrial Area at the time of the occurrence. The air pollution distribution patterns were predicted using a trajectory-geospatial method, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and Geographic Information System to account for the impact of the monsoon by determining which areas might be hit the worst as the shifted of monsoon seasons. Based on the results, the forward-air mass trajectories showed direct influence by the wind changes in monsoon seasons (Southwest Monsoon, Northeast Monsoon, and Inter-Monsoon). The geospatial maps showed the potential areas affected by the air pollution incident were highly distributed within 1 km, associated with lower dispersion of air pollution at 1000 m above ground level height. The findings can serve as a guideline for local authorities in decision-making to develop better standard operating procedure in managing future air pollution threats and to improve industrial location planning in reducing air pollution impacts on the surrounding area.

Keywords: Air pollution; monsoon; forward-trajectory; HYSPLIT; geospatial

INTRODUCTION

Air pollution has been a concern from the local to global levels due to the serious repercussions on human health and the environment. Long exposure to air pollutants leads to a higher risk of developing skin or eye allergies, breathing difficulties, cardiovascular diseases, stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases, and respiratory infections, including pneumonia (Chen et al. 2016; Gu et al. 2019; Haque & Sing 2017; Manisalidis et al. 2020). The severity of the air pollution issue should be addressed thoroughly since previous studies have shown a strong relationship between air pollution and the high global mortality rate (Khomenko et al. 2021; Lelieveld et al. 2015; Strak et al. 2021; Zhang et al. 2017). According to the World Health Organization (WHO), 9 out of 10 people breathe polluted air, resulting in around 7 million people dying every year from the exposure to fine air pollutant particles that penetrate deep into the lungs and cardiovascular system (World Health Organization 2018). The WHO report continues to issue an alert when more than 80% of persons living in urban areas are found to be exposed to air quality levels that exceed the WHO guideline limits (World Health Organization 2016). This growth in the global population influences economic expansion, putting pressure on the environment and resulting in the emissions of air pollutants from transportation, industrial, commercial, and residential sources all over the world (Ismail et al. 2017; Jorquera et al. 2019, Angelevska et al. 2021). Since then, industrialization has undergone fast development, particularly in the developing countries with the advancing technologies and expanding variety of industries.

Malaysia is one of the developing countries where air pollution is caused by a variety of causes, including vehicular and industrial pollutants (Fujii et al. 2016). In Malaysia, Pasir Gudang in Johor is known to have the highest industrial activities. Pasir Gudang is surrounded by industrial, residential as well as congested roads; the levels of CO, SO_2 and NO_2 are higher than in other districts in Johor (Rahman et al. 2016). Consequently, Pasir Gudang has experienced similar air pollution incidents like other industrial cities as well. Several occurrences of air pollution have been reported in Pasir Gudang, including severe cases in March and June of 2019, disrupting the daily lives of the surrounding populace. Referring to the air quality report published by the Department of Environment (DOE) on 18th March 2019, the government of Malaysia had sent 30 monitoring teams formed by the representatives from the DOE and Department of Chemistry (DOC) to 42 primary and secondary schools to investigate and monitor the air quality level (Department of Environment 2019). While the case happened in June 2019, The Johor State Education Department has announced that all of the educational institutions in Pasir Gudang under the purview of the Ministry of Education Malaysia to be closed from 25th June 2019 to 27th June 2019 to address the sources of air pollution (Johor State Education Department 2019).

Although air pollution is contributed by human activities like industrial activities, meteorological conditions such as wind direction, wind velocity, wind turbulence, solar radiation, atmospheric temperature stratification, atmospheric stability, cloudiness, and atmospheric pressure are believed to influence the dispersion, deposition, dilution, and accumulation of air pollutants (Perez et al. 2020). The appropriate and different meteorological conditions like the atmospheric stability, boundary layer thickness, persistent wind speed, and stability of the pressure situation can significantly reduce or exacerbate atmospheric pollution, directly impacting human exposure. The wind related to the monsoon system is the most useful indicator in predicting the intensity of air pollution. The Asian monsoon is classified as the largest monsoon system around the world that influences the meteorology conditions in most Asian countries, especially Malaysia (Chen et al. 2020). There are two types of monsoons in Malaysia: the Southwest Monsoon occurs from late May to September, and the Northeast Monsoon occurs from November to March (Saadatkhah et al. 2014).

During the Northeast Monsoon, the East Coast of Malaysia normally receives a large amount of rainfall starting from November until March (Nursuhayati et al. 2013). According to the Malaysian Meteorological Department (MET Malaysia), the Southwest Monsoon is relatively dry as compared to the Northeast Monsoon (Met Malaysia 2020). The transition months between these two monsoons, which are April and October, are known as the inter-monsoon season (Met Malaysia 2020). As the monsoon winds change, the direction of the wind, the air quality, and the areas affected by the air pollution will change as well. The inter-annual variation of monsoon can influence the intensity and frequency of synoptic weather circulation, favouring worse air quality (Zhang et al., 2016). The Southwest monsoon occurs on the Australian continent in the winter season and on the Asian continent in the summer season. Thus, the low air temperature from the Australian continent creates high pressure, and the high air temperature from the Asian continent creates low pressure. This condition causes the winds to move from Australia to the northwest across the Indian Ocean, and while crossing the equator, the wind is deflected to the northeast, ultimately arriving at Peninsular Malaysia and the South China Sea (Masseran & Razali, 2016). The Northeast Monsoon occurs during the summer season on the Australian continent while the Asian continent is in winter. The low temperature of the Asian continent forms a high-pressure area while the high temperature of the Australian continent forms a low-pressure area. As a result, the wind moves from the high-pressure area of Asia to the low-pressure area of Australia. During this season, the winds blow across the South China Sea before reaching Malaysia. The direction and the movement of the wind in this monsoon bring heavy rain, especially to the East and South Coast of Peninsular Malaysia as well as the central Titiwangsa Ranges (Masseran & Razali 2016).

It is important to know the direction of air pollutant dispersion especially the areas close to residential areas. The air dispersion modelling system is often used to predict the air pollution dispersion direction, especially considering the meteorological factors. The NOAA HYSPLIT is a comprehensive modelling system for simulating simple air parcel trajectories as well as complex air mass transportation, dispersion, chemical transformation, and deposition scenarios. The HYSPLIT model is well-known as one of the most widely used atmospheric transport and dispersion. Previous studies have shown the application of the HYSPLIT model to determine the dispersion and deposition of a dust storm over Iran (Ashrafi et al. 2014), dispersion of iodine-131 throughout Dubna and Stockholm (Leelossy et al. 2017), dispersion of arsenic in particulate matter (Chen et al. 2013) and dispersion of particulate matter from mine sites in Namibia (Uugwanga & Kgabi 2021). The HYSPLIT system is also used by government agencies and researchers for academic and emergency response purposes, such as monitoring nuclear fallout, volcanic aerosol dispersion, and dust storms (Cross 2015). While the HYSPLIT system has been applied during air pollution crisis, all it does is generating air mass trajectories without any accompanying geospatial data to pinpoint exactly where the air pollution will yield the most detrimental effect. There has been a dearth of research analysing air trajectories with geospatial information. The decision-making for tracking the spread of air pollution and pinpointing affected areas can be aided by integrating a Geographic Information System (GIS) into the standard modelling approach (Patania et al. 2009; Badach et al. 2020).

Thus, this study attempts to forecast the air pollution dispersion pathway and the affected areas based on monsoon winds at one of the famous Malaysian industrial regions, Pasir Gudang by using the trajectory-geospatial approach. The affected area by the air pollution incident in March and June 2019 at Pasir Gudang Industrial Area will be determined using geospatial mapping by integrating geospatial information with the air mass trajectories pathway. The air pollution forecast will be the driver to improve the development of the Standard Operating Procedure (SOP) in managing future air pollution threats and to address the emergence of industrial air pollution issues, particularly in the industrial areas in Malaysia.

METHODOLOGY

LOCATION OF STUDY

This study was conducted at the Pasir Gudang Industrial Area located in the Pasir Gudang city of Johor, the fifth largest state in the southern Peninsular Malaysia (Figure 1). Pasir Gudang Industrial Area is demarcated by red colour in Figure 1. Pasir Gudang Industrial Area with the coordinate of 1.4587334°N, 103.8959348°E has 2005 licensed factories, from which about 250 of them are chemical-based (Shu & Lee 2019). Pasir Gudang Industrial Area is situated at a greater elevation than the surrounding residential neighbourhoods.

The city of Pasir Gudang is located in Johor, a flat state that is mostly mountainous and has 400 km of coastline along the east and west side of Peninsular Malaysia. Johor has warm weather, and the temperature rarely drops below 27°C, making it a popular tourist destination year-round. Rainfall in Johor averages between 2,208 mm and 2,374 mm per year (Pour Wahab & Shahid 2020). The population in the Pasir Gudang area has increased from 247,295 people in 2015 to 533,868 people in 2019 and is predicted to highly increase in 2025, indicating the demand in the industrial sector and the level of economic development (Pasir Gudang Municipal Council 2020). Thus, the air quality level in the densely developed Pasir Gudang Industrial Area is expected to influence the health of over 500,000 residents living in the surrounding residential areas.

FIGURE 1. The location of Pasir Gudang Industrial Area is surrounded by residential areas (The red colour indicates the coverage of the Pasir Gudang Industrial Area in Johor).

MATERIALS AND METHODS

This study was conducted by using the trajectory-geospatial approach as presented in the flow chart in Figure 2. The trajectory-geospatial approach is the integration between the air mass trajectory analysis and geospatial mapping in order to predict the air pollution trajectory pathway based on a meteorological factor (monsoon wind direction) and to determine the area affected by the dispersion of polluted air from the industrial air pollution source to the surrounding areas in the Pasir Gudang Industrial Area. This approach has been selected to determine the potential affected areas precisely with the addition of spatial information from the geospatial mapping.

RANGE OF MEASURES

Data collection is important to obtain a suitable range of measures to be used in the analysis. The range of measures illustrated in Figure 2 that consisted of time, location, spatial information, and meteorological factors were determined based on the air pollution incidents reported in the industrial area in Pasir Gudang. Based on the severe air pollution incidents in Pasir Gudang Industrial Area that occurred in March and June of 2019, the study period was set in March, April, and May 2019 (Department of Environment 2019). As the study attempted to determine the influence of monsoon wind directions, the indicated three months spanned all of the Southwest Monsoon, Northeast Monsoon, and Inter-Monsoon seasons as Malaysia's climate is characterized by two distinct monsoon seasons: the Southwest and Northeast Monsoons, two Inter-Monsoons period as well (Loo et al. 2015; MET Malaysia 2019).

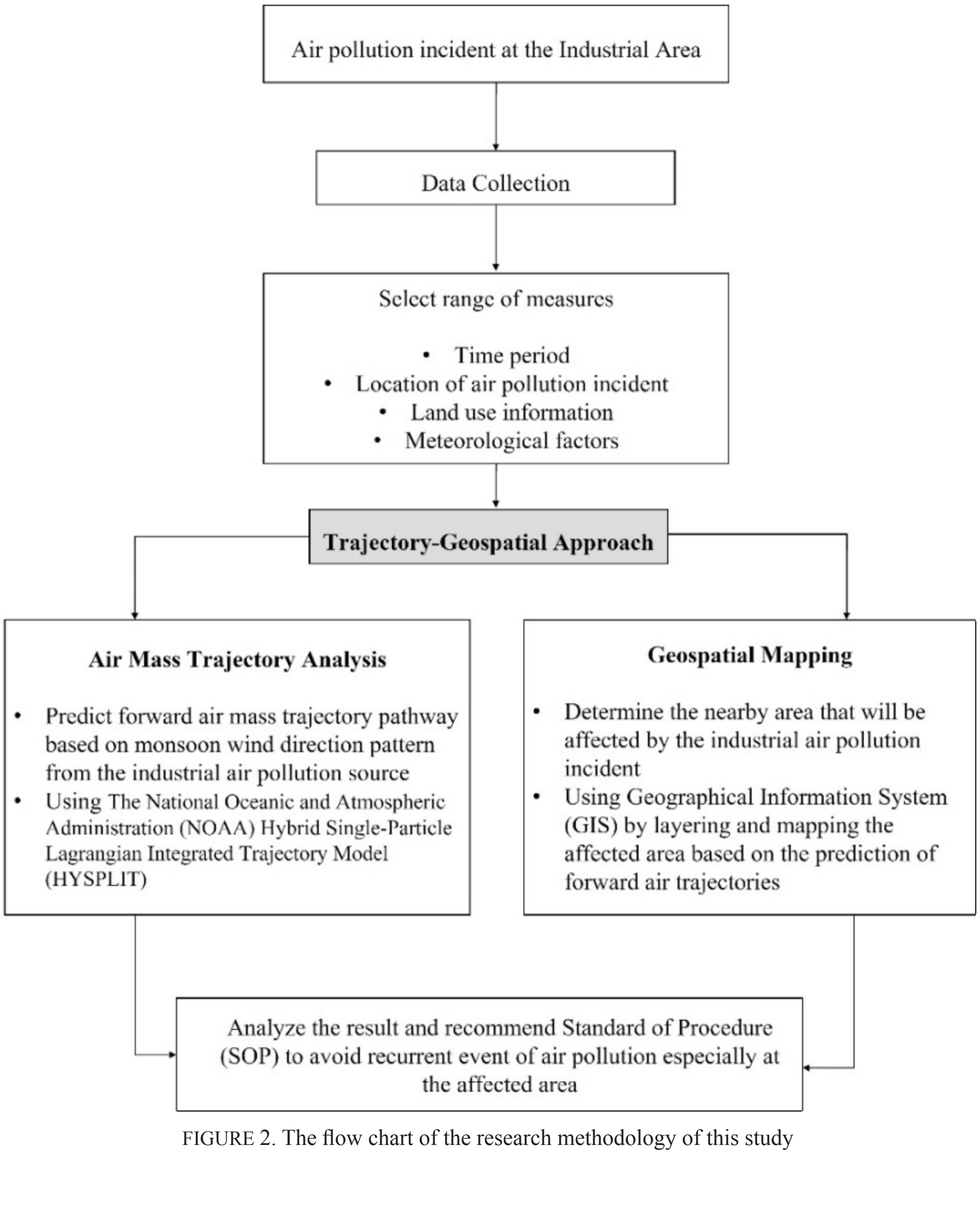

FIGURE 2. The flow chart of the research methodology of this study

AIR MASS TRAJECTORY

An air trajectory model namely The National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT) was used in this study to predict air mass trajectory pathway based on the monsoon wind direction (Figure 2). The air mass trajectories pathways were successfully obtained from the model and used to determine the potential area around the Pasir Gudang Industrial Area to be affected by air pollution. The NOAA HYSPLIT model simulates simple and complex air parcel trajectories, dispersion, chemical transformation, and deposition.

The HYSPLIT model is a popular atmospheric transport and dispersion model that has been widely used globally. The HYSPLIT model is often driven by meteorological data output from the Global Data Assimilation System (GDAS) that is used by the Global Forecast System (GFS) to place observations into a gridded model space for starting or initializing weather forecast with observational data (Su et al. 2015). The HYSPLIT model can determine almost 40 forward or backward trajectories at different altitudes of 500, 1000, 1500, 2000 and 2500 from above ground level (AGL) (Sharif et al. 2015). There are four trajectory types provided in the HYSPLIT model: normal, matrix, ensemble and frequency. In this study, normal and ensemble forward trajectories were used in the NOAA HYSPLIT model to predict the wind direction forecasts using the data from Global Forecast System (GFS).

GEOSPATIAL MAPPING

Geospatial analysis was conducted by adding the spatial elements to the forward air mass trajectories by layering using Google Earth Map to determine the affected area by air pollution in Pasir Gudang Industrial Area. The conducted normal trajectory would only start one trajectory from the first selected starting location whereas the conducted ensemble trajectory would start multiple trajectories from the first selected starting location. The ensemble trajectories can be very valuable to estimate the potential uncertainties of an individual trajectory in relation to the meteorological data surrounding the source location (Rolph et al. 2017).

DEVELOPMENT OF STANDARD OPERATING PROCEDURE (SOP)

This study also aimed to create a Standard Operating Procedure (SOP) as a control strategy based on the air pollution incidents that occurred in the Pasir Gudang Industrial Area, so that it could be used as a guideline by local authorities and other parties. The first stage in writing a SOP involved deciding on a structure for the document and finding the person in charge of this SOP, such as the local authorities, affiliated organisations and related parties. Next, the suitable analysis for air pollution prediction and detection of possible affected areas are chosen. Lastly, a decision-making process will be conducted once the interpretation of the analysis output was done. Once the SOP had been reviewed, any necessary changes had been made, and it was ready for implementation.

TABLE 1. The summary of wind direction forecasts from the forward-air mass trajectories

Month	Monsoon	Date	Wind direction	Affected area	Destination
		26 March	Southwest	Southwestern Pasir Gudang	Indonesia
March	Northeast	27 March	Southwest	Southwestern Pasir Gudang	Indonesia
		28 March	Southwest	Southwestern Pasir Gudang	Indonesia
		01 April	South	Southern Pasir Gudang	Indonesia
April	Inter-monsoon	07 April	North	Northern Pasir Gudang	Mersing, Johor
		09 April	Southeast	Southeastern Pasir Gudang	Pasir Gudang, Johor
		22 May	Northeast	Northeastern Pasir Gudang	Vietnam
May	Southwest	25 May	Northeast	Northeastern Pasir Gudang	China
		31 May	Northeast	Northeastern Pasir Gudang	South China Sea

RESULTS AND DISCUSSION

WIND DIRECTION FORECASTS

The HYSPLIT model has produced normal and ensemble type of forward-trajectories as illustrated in Figure 3 and 4, respectively, for three different months (March, April and May) in the Pasir Gudang Industrial Area. The normal trajectories only provided three members for possible offsets as represented as red, blue and green lines in Figure 3, indicating the movement of wind with a height of 500 m, 1000 m and above 1500 m above ground level (AGL), respectively. The ensemble trajectories provided 27 members for possible offsets with a height of more than 250 m AGL. The wind direction forecasts produced by the ensemble trajectories (Figure 4) were similar to the normal trajectories. The summary of wind directions forecasts from both types of forward-trajectories is shown in Table 1.

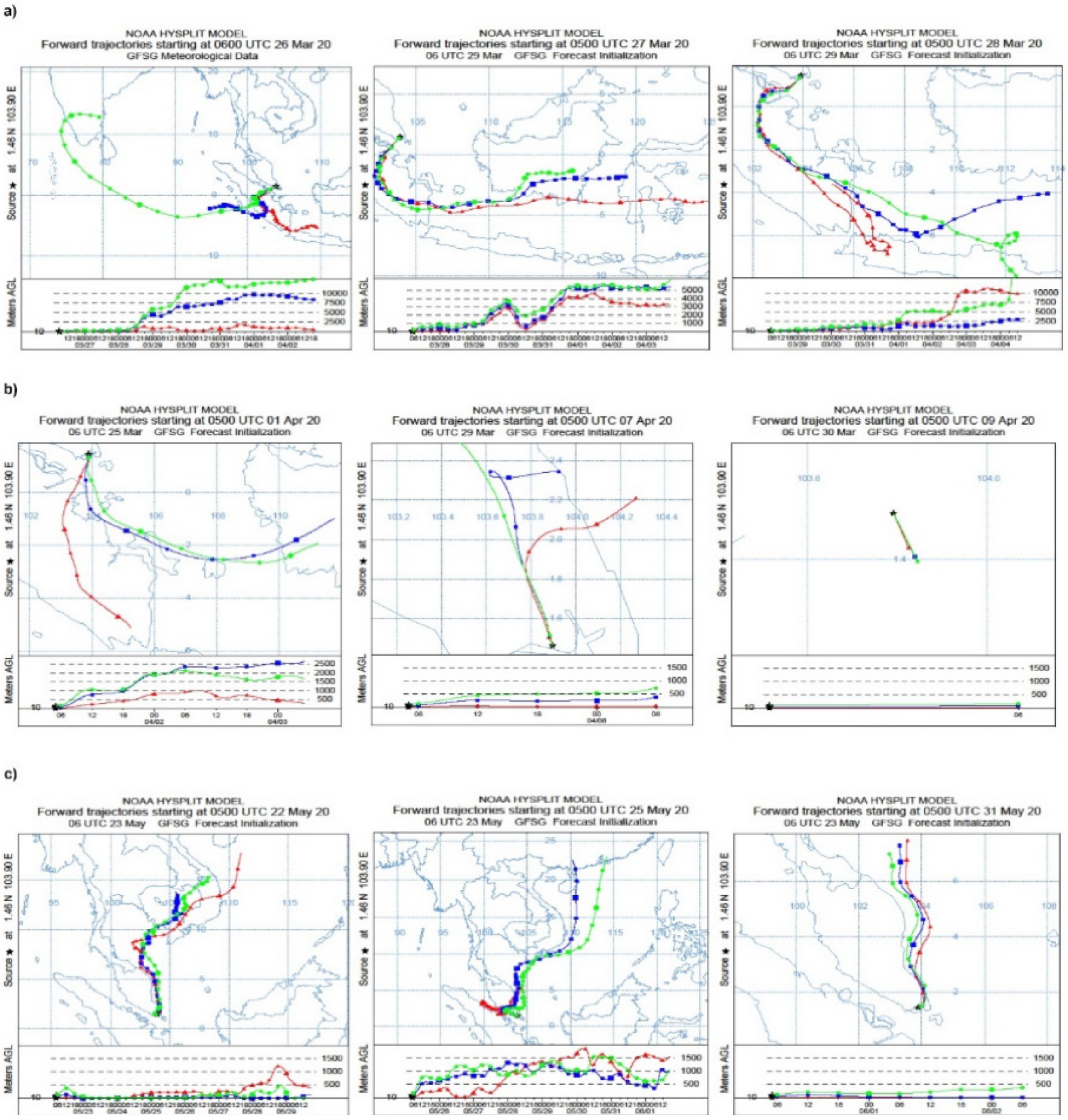

FIGURE 3. Wind direction forecasts produced by normal forward-trajectory using the HYSPLIT model for three different selected days in three months (March, April, and May). The air mass trajectories are colour coded based on the AGL trajectory release height (red = 500 m; blue = 1000 m; and green = above 1500 m).

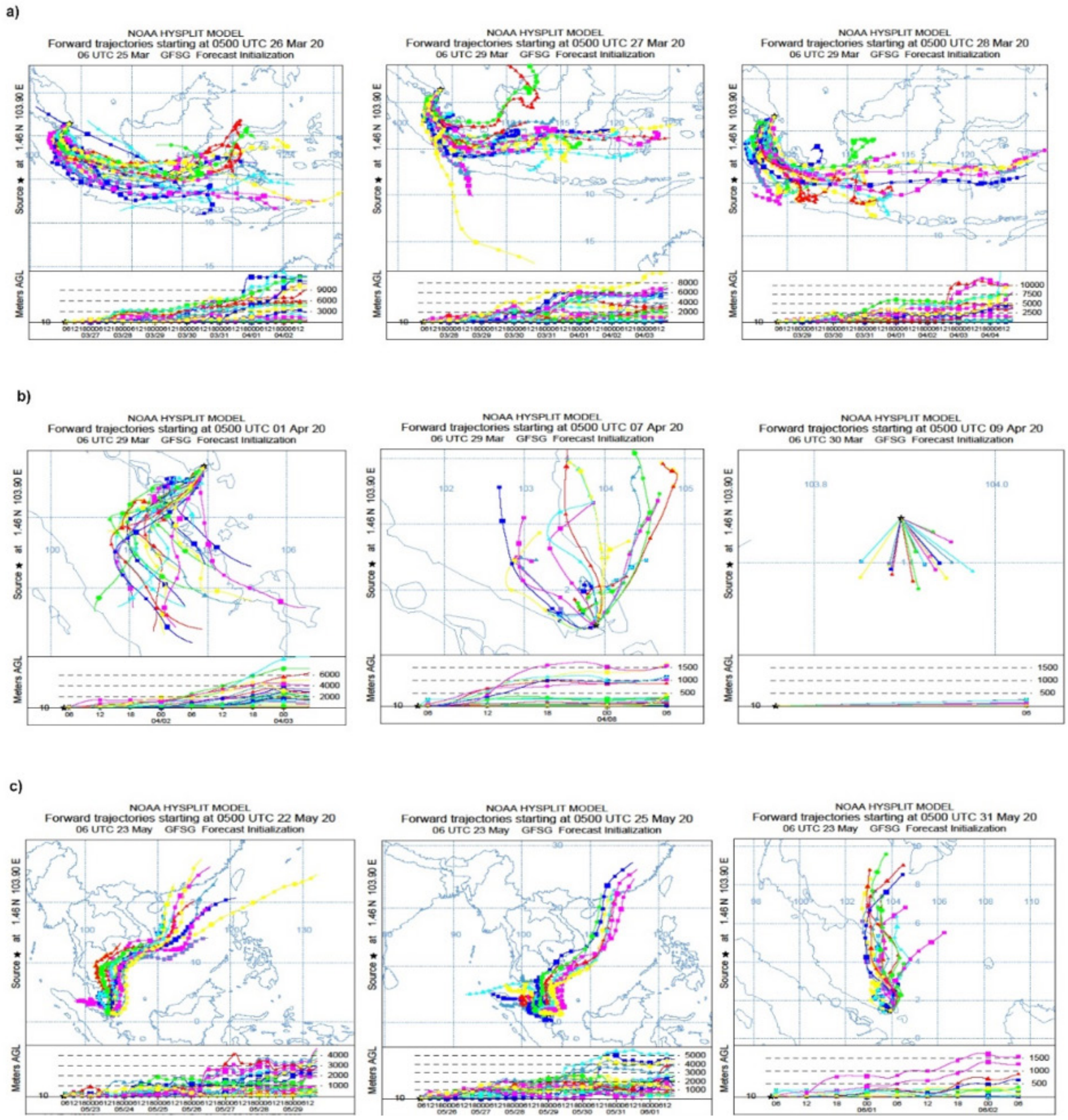

FIGURE 4. Wind direction forecasts produced by ensemble forward-trajectory using the HYSPLIT model for three different days in three months (March, April, and May). The air mass trajectories are colour coded based on the AGL trajectory release height (red = 500 m; blue = 1000 m; and green = above 1500 m).

In March, the results of both types of forward-trajectories (Figure 3 dan Figure 4) showed that the winds were stable, moving from the starting point (study area) to the southwest direction and thus passing through Singapore and stopping at Indonesia. The wind movement in March was influenced by the Northeast Monsoon season. During this season, the Asian continent's cold temperature creates a high-pressure area while the Australian continent's hot temperature creates a low-pressure area. The wind goes from Asia's high-pressure area to Australia's low-pressure area, forming the Northeast Monsoon (Masseran & Razali 2016). As a result, the findings in March in this study are true since they are similar to the idea of the Northeast Monsoon. Besides, the air mass trajectories in March 2019 were traveled at the higher level (AGL), above 1500 m AGL.

The results of both trajectories (Figure 3 and Figure 4) in April revealed that the wind directions were unstable, with winds blowing from the starting point (study area) to the south, north, and southeast on different days in April. The winds in April passed through the different areas and stopped at different destinations, such as Indonesia; Mersing, Johor; and Pasir Gudang, Johor. April is the inter-monsoon period. During the inter-monsoon transition, the wind direction will shift for a short duration, with rather weak wind conditions and speeds not reaching 10 knots, similar to the height of air mass trajectories in this study that show the air mass traveled below 1500 m AGL mostly (Masseran & Razali 2016; Ooi et al. 2019).

In May, both trajectories pathways (Figure 3 and 4) showed that the direction of the wind was stable, blowing from the starting point (study area) to the north direction first, and then switching to the northeast direction before finally stopping at Vietnam, China and the South China Sea. Theoretically, May falls in Southwest Monsoon (Dahari et al. 2020). During this season, the Asian continent's hot temperature creates a low-pressure area while the Australian continent's cold temperature creates a high-pressure area. The Northeast Monsoon is formed as the wind moves from Australia's high pressure area to Asia's low pressure area (Prasanna & Chidambaram 2021). This result was supported by another study in Malaysia which stated that the winds moved northward and then only changed into eastward when it approached the northern tip of Vietnam (Daryabor et al. 2014).

POTENTIAL AREAS THAT AFFECTED BY AIR POLLUTION

Following the wind direction forecasts from the previous air trajectories, the potential locations that might be exposed to air pollution must also be assessed in the study area, Pasir Gudang Industrial Area. Figure 5 until Figure 7 show the prediction of the potential areas in Pasir Gudang that will be affected by air pollution as produced by the normal and ensemble trajectory using the HYSPLIT model. Spatial information from Google Earth Map was important in order to determine the areas and land-use activities that would be affected by the transportation of the air masses from nearby areas.

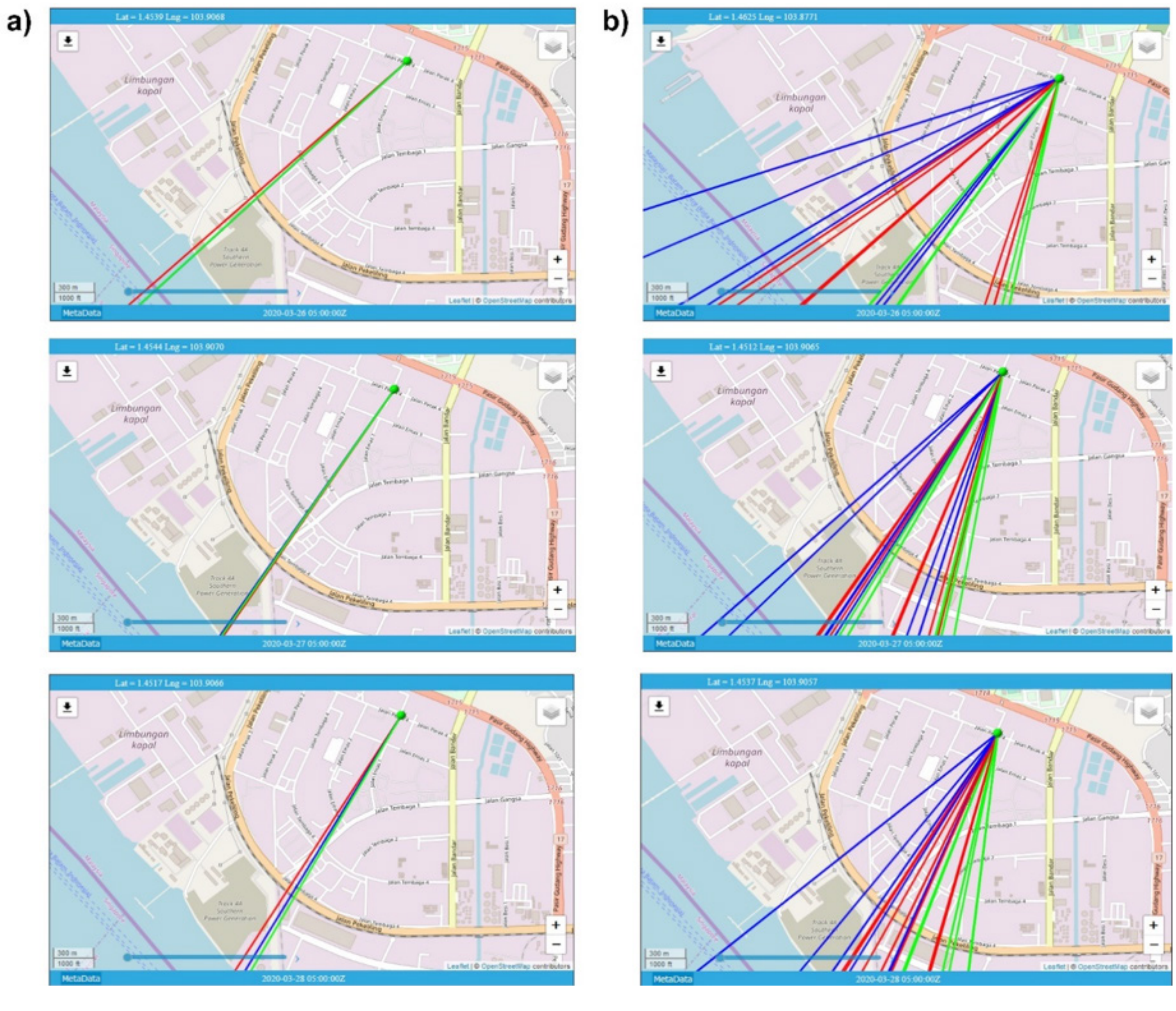

FIGURE 5. Potential areas affected by air pollution, analysed by trajectory normal in NOAA HYSPLIT model in March 2019. a) Normal air mass trajectories and b) Ensemble air mass trajectories. The air mass trajectories are colour coded based on the AGL trajectory release height (red = 500 m; blue = 1000 m; and green = above 1500 m).

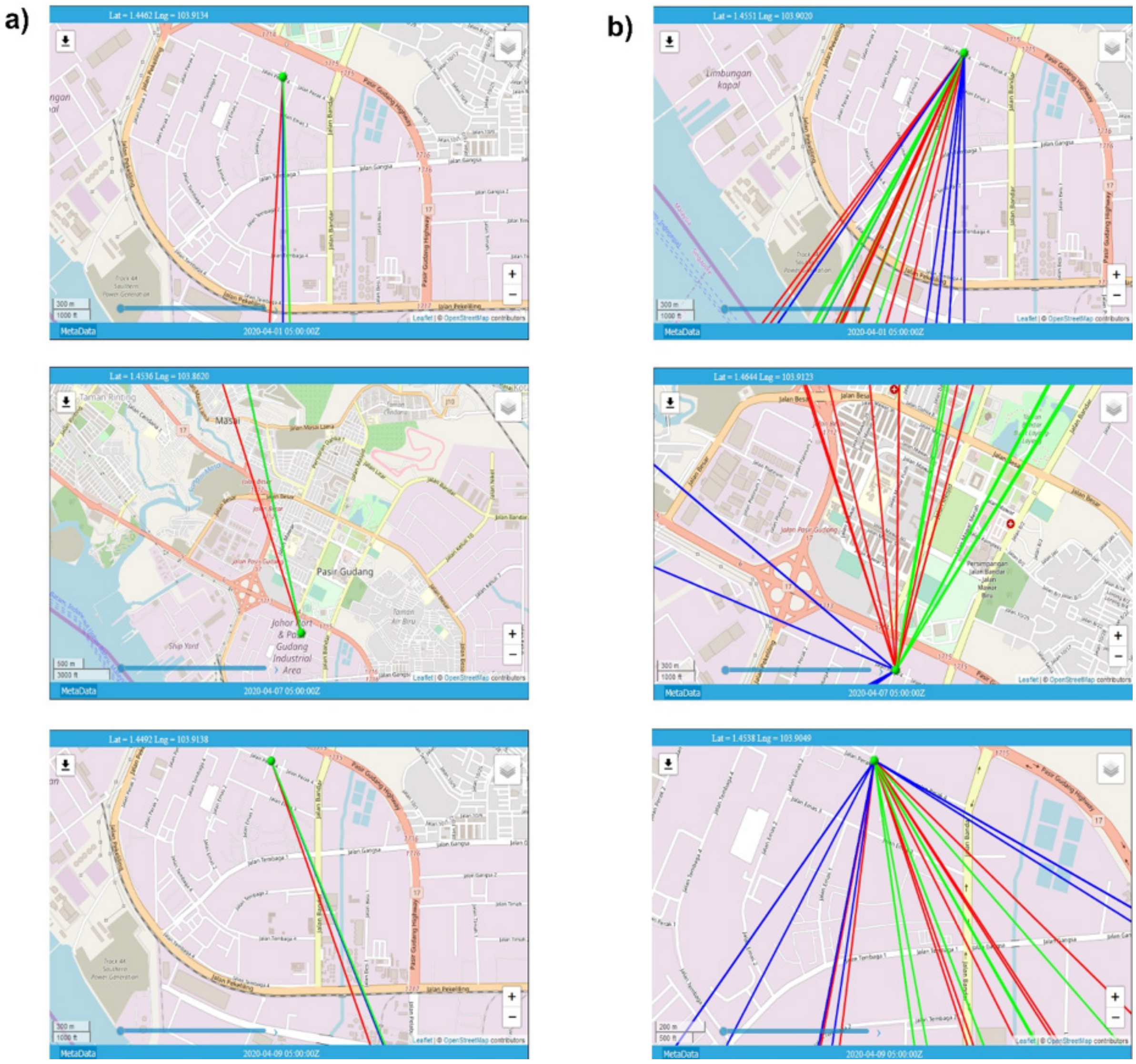

FIGURE 6. Potential area that is affected by air pollution, analysed by trajectory ensemble in NOAA HYSPLIT model in April 2019. a) Normal air mass trajectories and b) Ensemble air mass trajectories. The air mass trajectories are colour coded based on the AGL trajectory release height (red = 500 m; blue = 1000 m; and green = above 1500 m).

Both normal and ensemble trajectories in Figure 5 showed that the winds were blowing to the southwest direction in March, indicating that the southwestern of Pasir Gudang Industrial Area had the potential to be exposed to air pollution. Although there is no residential area, but only a restaurant and a few factories located in the southwestern of Pasir Gudang, the air pollution exposure is predicted to influence the air quality level surrounding the factories and nearby areas. This could contribute to the increasing air pollutant concentration in those areas since there are still air pollutant emissions from nearby factories and traffic. Previous studies showed that the rising air pollution levels, especially in the industrial areas, are due to strong industrial background sources, high traffic emissions and persistent inversion during the Northeast Monsoon (Bodor et al. 2020; Chen et al. 2015; Cichowicz et al. 2017).

In April, both normal and ensemble trajectories showed the influence of inter-monsoon effects on air masses transportation. Since the wind directions were unstable and the air masses travelled at low height, the potential areas affected by air pollution varied in the directions. The results in Figure 6 showed that the inter-monsoon winds were predicted to transport the air mass pollutants to the northwest and southeast direction. The forecast predicted the area in the northwest, including the education institutions and residential areas, such as Universiti Teknologi Mara Pasir Gudang, Taman Mawar, Taman Seri Alam, and SMK Seri Alam 2 was potentially facing the exposure of air pollutants transported from the nearby local and transboundary sources. Meanwhile, the air masses were also predicted to be transported to the southeast of Pasir Gudang where Kampung Pasir Putih and Pasir Gudang Port are located. During inter-monsoon, the winds were forecasted to transport the air pollutants to various directions (Prasanna & Chidambaram 2021). Furthermore, when the weather during the inter-monsoon is humid, it will raise the ambient temperature in Malaysia, particularly in the afternoon, influencing the accumulation of air pollutants (Latif et al. 2012).

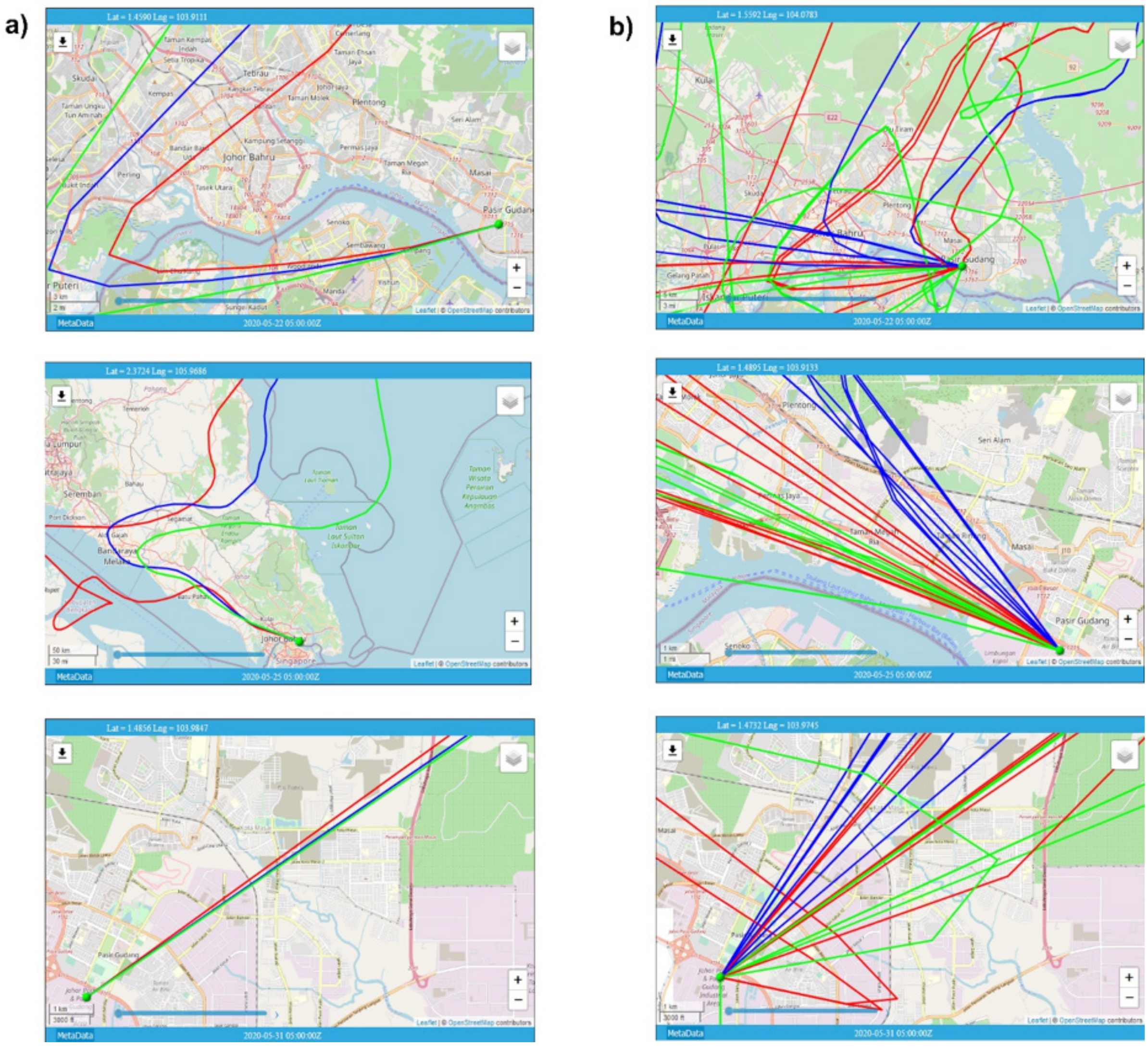

FIGURE 7. Potential area that is affected by air pollution, analysed by trajectory ensemble in NOAA HYSPLIT model in May 2019. a) Normal air mass trajectories and b) Ensemble air mass trajectories. The air mass trajectories are colour coded based on the AGL trajectory release height (red = 500 m; blue = 1000 m; and green = above 1500 m).

During the Southwest Monsoon in May, Figure 7 shows that the dominant wind directions are all towards the northeast direction. However, the movement of air mass pollutants on 22nd May was expected to move to the southwest, then shifting to the northeast while on 25th and 31st May, the air mass forward-trajectory pathways showed a movement to the northeast direction. This was due to the Southwest Monsoon, which began at the end of May and lasted until September. The wind patterns on 22nd and 25th May clearly showed that the inter-monsoon started to change to the Southwest Monsoon. Due to the transition of monsoon season at this period, the potential areas affected by air pollution in these three days in May were different. From both normal and ensemble forward-trajectories in Figure 4 and Figure 5, the air mass movements were expected to most likely pass through the residential areas, such as Kampung Pasir Gudang Baru, Kampung Sungai Rinting, Taman Rinting, Taman Megah Ria, Taman Pasir Putih and Taman Kota Masai. The result for May in this study was supported by the study in Vietnam, showing similar wind patterns during the period of the changing of inter-monsoon to Southwest Monsoon (Nguyen-Le et al. 2014).

RECOMMENDATION OF STANDARD OPERATING PROCEDURE (SOP) IN MANAGING AIR POLLUTION THREATS IN INDUSTRIAL AREAS

Based on the trajectories-geospatial approach conducted in this study, the normal and ensemble trajectory using the HYSPLIT model and geospatial mapping were able to forecast the movement of air mass pollution from the sources towards the nearby areas. Since Pasir Gudang has frequently experienced severe air pollutant incidents that affected the health of the residents (Ismail et al. 2020), this approach is essential to be applied under a proper Standard Operating Procedure (SOP) that involves related stakeholders, especially local authorities. Figure 8 shows a flowchart of recommended SOP to address action plans in managing air pollution threats in industrial areas.

The SOP in Figure 8 is recommended to be used when there is air pollution exposure from industrial sources, like leakages of chemical or gaseous substances. The first step is to determine whether there is a case of air pollution threats that possed hazardous level of air pollutants towards human health and environment. If no air pollution threat occurs, the business is run as usual (industries, educational institutes, government institutions and others can be operated as usual. If the are air pollution threats such as leakage of chemical or gaseous substances that can lead to severe air pollution impacts, the local authorities and related parties must take action to determine which the source of air pollution threats and the possible affected areas. The source of air pollution threats that come from industrial regions that are suspected of contributing to the arising of the hazardous level of air pollutants is advised to be temporarily closed until further notice.

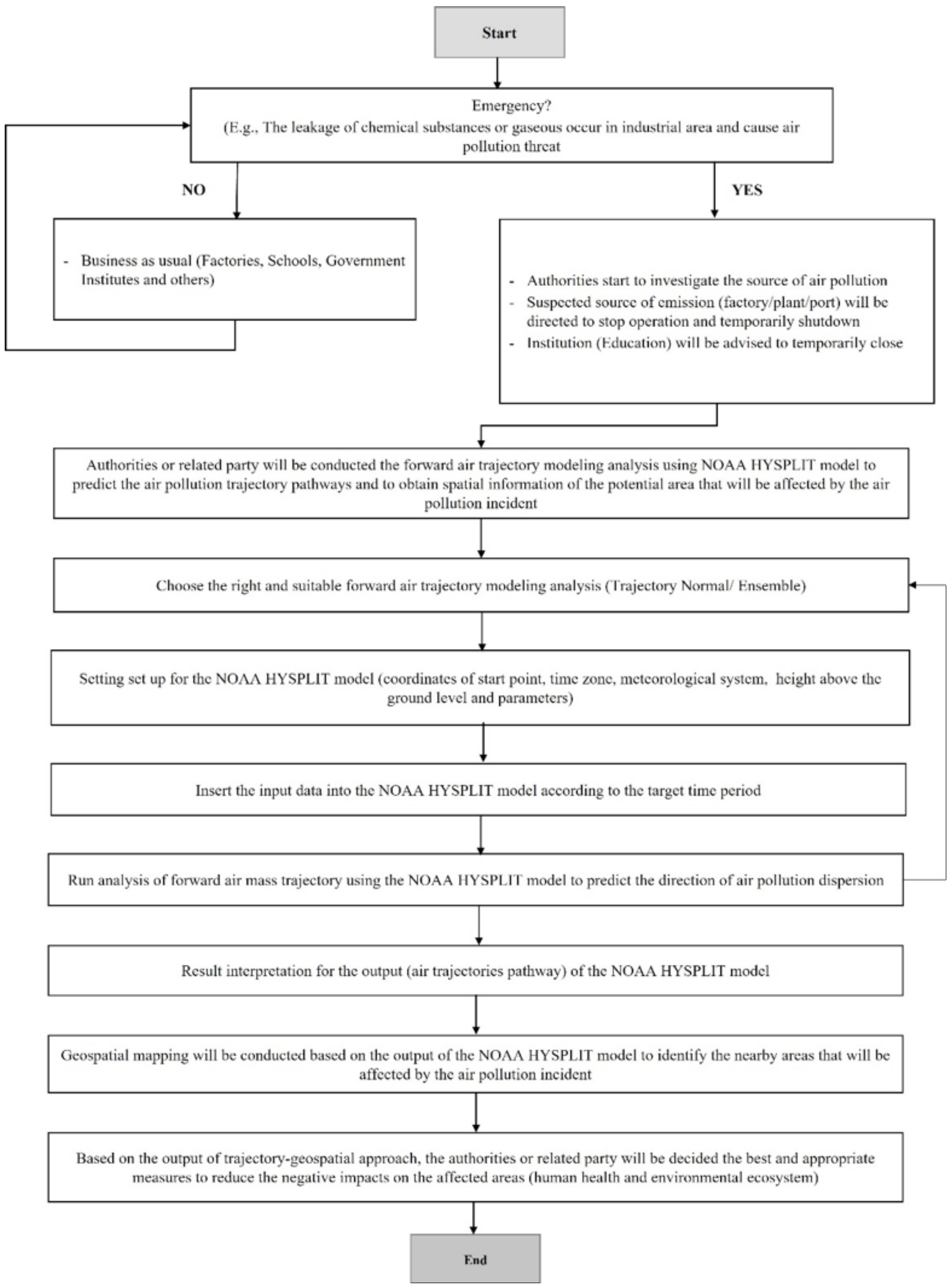

FIGURE 8. The recommended SOP in managing air pollution issues in the industrial regions.

Following that, the authorities or related parties will use an air trajectory model, the NOAA HYSPLIT model, specifically the normal and ensemble forward-trajectory as the forward-trajectory would forecast the movement of air mass pollutants to predict the wind direction and potential areas affected by the air pollution incident in order to minimise the negative effects of air pollution on locals (Dodla et al. 2017; Kulshrestha & Kumar 2014). The NOAA HYSPLIT model requires the location of the industrial air pollution source (industrial factory/plant), the UTC (Universal Time Coordinated) time zone, the trajectory meteorological system and the selected parameters to determine the wind direction pathways of air pollution dispersion. Then, the geospatial mapping is advised to be conducted with the geospatial analysis to identify the potentially affected areas that will be exposed to the air pollution incident.

Based on the output interpretation, the authorities or related parties can take proactive and appropriate measures to reduce the negative effects of air pollution on human health and the environment. Until the air pollution exposure problem is solved, the authorities or related parties are advised to conduct regular air quality monitoring to monitor the ambient air quality level. Compliance with the proper and systematic SOP for managing air pollution threats from the industrial regions, prediction of the air pollution dispersion pathway and potentially affected areas is one of the best actions in air quality management, particularly from industrial emissions, since the industrial areas are known to discharge air pollutants emissions.

The recommended SOP can help reduce the effects of air pollution exposure on residents by acting quickly to resolve the air pollution threats in addition to acting as a guideline for all stakeholders involved. It is also essential to understand better strategies for monitoring and mitigating industrial air pollution (Sofia et al. 2020; Wang et al. 2018).

CONCLUSION

This study was able to prove that by applying the air mass forward-trajectory in the HYSPIT model, the wind direction of air mass pollutants can be predicted in a few days from the point source in Pasir Gudang Industrial Area. The results from the wind direction forecasts analysis have shown the influence of monsoon winds during the three months (March, April and May) of the study period. The wind movement of air mass pollutants in March was influenced by the Northeast Monsoon. The air mass forward-trajectories pathways in April have been influenced by unstable inter-monsoon winds during inter-monsoon, leading to a variety of wind directions at lower height of AGL (m). The Southwest Monsoon has been identified to influence the wind movements of air mass pollutants as shown by the forward-trajectories of air mass pathways in May.

By using the geospatial mapping in GIS, the areas in Pasir Gudang that would be affected by the transportation of air mass pollutants from the sources were able to be determined. The geospatial information in Google Earth Map, layered with the air mass forward-trajectory in both trajectories' types (normal and ensemble), has eased the identification of affected areas. From the forecast, the wind direction in March would bring the air mass pollutants to the southwest of Pasir Gudang while the wind direction in May would move the air mass pollutants to the northeast. The inter-monsoon winds in April has been identified to bring the air mass pollutants to different directions at a lower height of AGL (m) until most of the affected areas are highly distributed at below 1 km as the wind is unstable and lower air pollution dispersion.

From the findings, a standard operating procedure (SOP) for addressing and managing future air pollution incidents in industrial areas, particularly in Pasir Gudang Industrial Areas, using a trajectory-geospatial approach has been developed as an action plan for the involved stakeholders. This SOP is necessary and beneficial if there are chemical or gaseous leakages from the industrial areas. The recommended SOP can reduce the exposure to air pollution threats by acting fast to mitigate the effects of air pollution and solve the air pollution incident. In addition, the recommended SOP serves as a guideline for all parties involved to understand and improve ways to monitor and mitigate industrial air pollution.

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DECLARATION OF COMPETING INTEREST

None

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