Distinguish Potential Source Areas of PM$_{2.5}$ and PM$_{10}$ by Statistical Data Analysis

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Abstract. Power plant from biomass in community area has been complained as emission source of many pollutants such as wastewater, noise, odor and polluted air. For air pollution, total suspended particulate (TSP) and particulate matter less than 10 micron (PM$_{10}$) from rice husk energy process is quite large. Roi Et is a province located in Northeast of Thailand which obtains power plants using rice husk as fuel in the process. According to the land-use pattern of the community area of Roi Et, it revealed that there are many sources of air pollution. This study selected the statistical techniques to distinguish the potential source area influencing the high concentrations of particulate matter less than 2.5 micron (PM$_{2.5}$), particulate matter 2.5 to 10 micron (PM$_{coarse}$), and PM$_{10}$ which caused the health effects of people around the rice husk power plants. Hourly observed PM$_{10}$ and PM$_{2.5}$ data were analysed by time series and bivariate polar plot. Results showed that increasing the concentration of PM$_{10}$ and PM$_{2.5}$ were observed in the duration of low wind speed. However, daily average of PM$_{10}$ was not more than National Ambient Air Quality Standard (NAAQS) which is 120 µg/m$^3$. In contrast, results showed that daily average of PM$_{2.5}$ performed over NAAQS of 50 µg/m$^3$ in the 20$^{th}$ - 22$^{nd}$ December 2018 that high pressure cover Thailand. While sources of these particulate matters could be distinguished into 3 potential areas based on the mobile air quality monitoring station location which were 1) east side and 2) north-west side which regarded as sub-urban and traffic areas, respectively and 3) north-east side which regarded as power plants area. Results revealed that PM$_{coarse}$ was the major pollutant dispersed from the Northeast direction that the power plants were the major source. Whereas traffic and community were the main sources of PM$_{2.5}$ coming from the East and the Northwest direction of the mobile air quality monitoring station point. Therefore, discrimination of each point source could be done first before implementing to control and manage the air pollution effectively.

Keyword: PM$_{10}$, PM$_{2.5}$, Bivariate polar plot, rice husk power plant

1. Introduction
Today, air pollution problem resulted from expansion of energy sector; especially biomass power plant has been listed to be concerned. Because Thailand has various types of biomass that can be used
to generate many alternative energies. Rice husk is the by-product from the rice mill, community rice mill and steamed rice mill. In each year, the 25 million tons of paddy products can produce 5.75 million ton of rice husks [1]. Rice husk is an optional fuel in direct combustion to produce an energy source for the large rice mills. Currently, rice husk has been used as fuel to generate electricity that the quantity of 9,800 ton of rice husks can be used for production 1 MW of electricity. There are rice husk biomass power plants has operated in Roi Et province that located in Northeast of Thailand. The rice husk biomass power plants located in community area has been complained as emission source of many pollutants such as wastewater, noise, odor and polluted air [2]. For air pollution, total suspended particulate (TSP) including particulate matter from rice husk energy process of power generation is quite larger than emission from the process using coal fuel [3]. Although dust, which including PM$_{10}$ and particulate matter less than 2.5 micron (PM$_{2.5}$) at the community in the Nuea Mueang sub-district, Roi Et province were regarded to be mainly from power plants in the past. This was argued by the surrounding communities, and they believed that there is impact of dust emission affecting to them. The community has started to ask the provincial government and the enterprises to solve the environmental problems [2]. However, the land use of this area is revealed that there is spatial complex. Community and transportation in the area play the crucial sources of combustion and then result in the overall particulate matter concentration, as well. To implement the proper regulations and policies, potential source areas affecting air pollution in the community near the power plants would be identify.

Therefore, this study aimed to identify the potential source areas of PM$_{10}$ and PM$_{2.5}$ using integrated statistical techniques and bivariate polar plot. The statistical technique using bivariate polar plot is beneficial method to recognize source characterization in a complex emission area, and performs filtering air pollution data associated with wind speed and direction during the period of interest. Thus, they can prove the directional sources in a specific time period [4, 5, 6]. Results from this study are expected to be applied for the policymaker to reduce, control and management of PM$_{10}$ and PM$_{2.5}$ in the Roi Ed and the others, which have more complex emission area of air pollution.

2. Study area and methodology

The study area of this work focuses on the Nua Mueang sub-district, Roi Et province that located in the northeastern part of Thailand. There are adjacent air pollution mobile, point, and residential sources, which affecting to surrounding community by their emissions. Major point sources are rice husk biomass power plants located in one plot of the area of 300 m$^2$ as shown in Figure 1. Their capacities are 9.95, 6.00, and 9.90 MW, respectively [2]. Whereas, the requirement of Thailand regulation to perform the environmental impact assessment (EIA) enforces for the power plant larger than 10 MW in capacity. Three of them were not assessed by the EIA. However, it does not mean that there is no pollution emitting from the small power plant (less than 10 MW) [2].

The data of this study was obtained by the mobile air quality unit of the Environmental Research and Training Center, Thailand during 18-21 December 2018. This period is winter season that is the affected period by the power plants to communities [2]. The mobile unit had been installed at the Nuea Mueang sub-district, Roi Et province to monitor PM$_{10}$, PM$_{2.5}$, wind direction, and wind speed. The unit equipped with the Thermo Scientific™ 1405-DF TEOM™ Continuous Dichotomous Ambient Air Monitor equipment and meteorological equipments. The location of the monitoring station located in the north of the Roi Et urban area, and in the southeast direction of the power plants area (Fig. 1). During the monitoring period, the dominant wind over Thailand is governed by the northeast monsoon [7]. Therefore, most of the wind blowing during this period would be coming from the northeast side to the station.

The hourly observed data obtained by the station were analyzed to present the variations of their parameters in order to understand the air pollution situation of the study area. To distinguish potential source areas affecting each observed particulate matters (PMs), the R program [8] with the bivariate polar plot function of the OpenAir package [9] was utilized.
The bivariate polar plot is a plot of the interesting statistical metric on the polar coordinate. The coordinate systems are commonly used to visualize the data at the corresponding pair of axes on a plan as a spatial map. The polar coordinate system uses radial (r) and angles (θ) axes. For the air quality analysis, the radial axis (r) can be applied to represent wind speed and the angular axis (θ) be applied to represent wind direction. The interesting statistical index, an average of maximum concentration of the PMs for this study, in each corresponding ranges of wind speed and wind direction is plotted at the corresponding coordinate in the polar coordinate system. Also, the result can be compared with the aerial image to determine the consistency of the emission sources influencing the level of pollutant at the air quality monitoring station [5], but the plot in the polar coordinate system cannot be compared with the measurement value as the air quality dispersion model [10].

3. Result and discussion
The data obtained during the monitoring period (18-21 December 2018) were used for analysis. Firstly, wind circulation is an important factor used to present where the frequented wind direction that brings air mass to the monitoring station. Figure 2 presents the wind rose of the study period, which reveals the wind blows from the North side till the Northeast sides more than 50%, and especially coming from the Northeast 20%. The calm condition contributes 26% of the total, which results in less air mass transportation. The variation of wind speed shows in Figure 3, its range is between calm to 4 m/s.

Changes in the hourly average concentrations of the PM_{10} and PM_{2.5} present in Figure 3. It is noteworthy that the variation of PM_{10} and PM_{2.5} occur at similar times. This would imply to the same forcing factor impacting the levels of both pollutants. While the variation of wind speed is low or in the calm condition during the pollutants become high concentrations. This coincident most occur during on the night time. Not only the signal of diurnal variation can be observed in the PM_{10}, PM_{2.5}
and wind speed variations, but also there is a signal of daily timescale variation envelops in their fluctuation. Therefore, the 24 hours rolling average was performed to the PM$_{10}$, PM$_{2.5}$ and wind speed data to remove the noise of diurnal variation. The advantage of using this technique does not only remove the noise, but the 24 hours rolling mean concentration can be compared to the NAAQs of PM$_{10}$ and PM$_{2.5}$ as shown in Figure 4.

**Figure 2.** Wind rose

**Figure 3.** Time Series of PM$_{10}$, PM$_{2.5}$, and wind speed (WS).
Figure 4. Time Series of 24 hours rolling average of PM$_{2.5}$ and wind speed (WS). The red dash line is the NAAQs of PM$_{2.5}$.

The NAAQs of PM$_{10}$ and PM$_{2.5}$ of Thailand were set at the levels of 120 µg/m$^3$ and 50 µg/m$^3$ in 24 hours average, respectively. Both averages of PM$_{10}$ and PM$_{2.5}$ found that the change in the average concentration of PM$_{10}$ does not exceed the standard value, while the average concentration of PM$_{2.5}$ exceeds the standard value of 50 µg/m$^3$ during 20-22 December 2018. The daily variations of pollutants without the diurnal noise are obviously shown that the high concentrations of PM$_{10}$ and PM$_{2.5}$ coincided with the occurrence of low wind speed. Very low wind speed or calm condition results in more strengthening of high concentrations of PM$_{10}$ and PM$_{2.5}$ than that of low wind speed (Figure 4).

From the analysis mentioned above, it was found that the main wind direction is the northeast wind blowing through the monitoring station. The concentration of PM$_{10}$ and PM$_{2.5}$ in the measurement area will increase during the low wind speed, but still does not know where the potential source areas are. There are mobile, residential, and point sources located around the community represented by the monitoring station. Impacts of them on the ambient air quality at the monitoring station area would be different. Therefore, analyzing the bivariate polar plot was applied for the observed data of PM$_{10}$, particles of 2.5-10 microns (PM$_{Coarse}$) and PM$_{2.5}$.

The result of bivariate polar plot analysis presents in Figure 5. It was found that the source area (red shading) of PM$_{10}$ originating from the east and north-west of the measurement point (Figure 5a). The east side is a community suburb area that having high traffic density and residential activities related to emit PM$_{10}$. For the north-west side, the red shading similar to the line, and corresponds to the line of highway on the aerial image. This means that the mobile source plays an important role in releases PM$_{10}$ affecting the community at the Nuea Mueang sub-district. For the red shading presents on the east side, it related to the suburb of Roi Et province that can be seen in the aerial image. It implies to the activities in the suburb area affecting the PM$_{10}$ level as well. It is noteworthy that there is red shading as a point on the northeast side. Air pollution source in the northeast side is the power plants establishment, which collocated in the same place of the shading.
While the source area of PM$_{2.5}$ (Fig. 5b), which is a particle that is smaller than 2.5 microns and is part of the PM10, found that the source is from the east and the northwest above the measurement point. These imply that the potential sources related to activities in suburb area and traffic in the highway, respectively. The power plants are not the potential source contributing PM$_{2.5}$ to the monitoring station. For particles having size from 2.5-10 microns (PM$_{Coarse}$), The result reveals that the potential source of the PM$_{Coarse}$ comes from surrounding area near the monitoring station and the northeast area (red shading in Fig 5c). The light red shading close around the monitoring station corresponding to the residential sources that have activities such as burn weeds, cooking by firewood or charcoal stove, and light traffic. The red shading is in northeast side are the power plants and contributing more than the residential sources, which indicating by darker shading (Fig. 5c).

Figure 5. Bivariate polar plots of PM$_{10}$, PM$_{2.5}$, and PM$_{Coarse}$, respectively. Shading presents the averaged maximum concentration.
4. Conclusions

The resident living at Nuea Mueang sub-district, Roi Et province, Thailand has been facing air pollution during winter season. The air quality monitoring station representing the living area was installed in the community near power plants locating in the northeast direction. The analyses of observed PM$_{10}$, PM$ _{2.5}$ and meteorological data revealed that the high concentration of PM$_{10}$ and PM$ _{2.5}$ present during the period of low wind speed and high pressure. The meteorological factors are an uncontrollable factor. But, a source of pollutant is important to select the appropriate solution to control the real situation of air pollution and should know where the potential source areas affecting the community are. The BVP analysis was applied to distinguish potential source areas that contribute particulate matter to the community. This found that PM$ _{10}$ originating from the east, northwest and northeast of the measurement point that are related to the traffic and activities in suburb area, mobile source at the highway, and power plants, respectively. Whereas, potential source areas of PM$ _{2.5}$ present at the east and the northwest sides, which imply to the activities in suburb area and mobile source at the highway are potential sources. For PM$_{\text{coarse}}$, the potential source of the PM$_{\text{coarse}}$ comes from the residential sources near the station and the power plants. Therefore, the small particle (PM$_{2.5}$) that the community facing is from the activities in the suburb area in the east side and traffic on the highway in the northwest side. The larger particle (PM$_{\text{coarse}}$) comes from the residential sources near the station and the power plants. From this study of Roi Et province, results indicated that not only control emission source of power plants, but community and traffic could be concerned and required to reduce the PM$_{10}$ and PM$_{2.5}$ level by using the appropriated policy for each pollutant sources.

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