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Coal dust exposure characteristic and impact on respiratory impairment from coal unloading station in Palembang, South Sumatra, Indonesia

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Abstract

Coal hauling, loading, and transportation activities impacted the emergence of coal dust which is harmful to health. Coal dust exposed from coal unloading stations and coal waterway transportation is escaped attention. This study aimed to determine the characteristics of coal dust, the influence of climate parameters on the spread of coal dust, and its impact on the health of children under five in the exposed area. Coal dust characteristics and concentrations of PM $PM_{2.5}$ and PM_{10} were analyzed from ten points spread across three mining companies (A, B, and C). The effect of climate parameters on $PM_{2.5}$ and PM_{10} was tested statistically. The results of the chemical analysis revealed that coal dust was dominated by the high content of Si, Al, S, and Fe. The concentration of $PM_{2.5}$ and PM_{10} is affected by wind speed. $PM_{2.5}$ and PM_{10} can exceed the annual threshold value, which has caused a high incidence of respiratory problems in two sub-districts, namely Makrayu and Gandus.

Keywords: coal dust, particulate matter, coal transportation, respiratory disorders

Introduction

Coal is a reliable source of abundant energy and an asset for Indonesia. Coal has played an essential role in power generation and is a necessary fuel for producing steel, cement, and other industrial activities. Around 60% of the world's steel construction and 40% of power generation are currently powered by coal (Mahdevari & Shahriar, 2016). One of the important issues involved in coal mining operations is coal dust, which can cause a series of health problems (Yao et al., 2020). Almost all mining processes are accompanied by the appearance of coal dust (Shahan & Reed, 2019).

Fine particles are a concern because the concentration of $PM_{2.5}$ and PM_{10} has increased due to industrial developments and human activities, especially particulate matter from coal dust which is harmful to health. Coal dust is the most significant hazard associated with mining activities (extraction processes, blasting operations, drilling, cutting, ore transport, or by mechanical means during handling) (Fan & Liu, 2021). Wind speed, moisture content, and mechanical handling are some of the factors associated with the amount of coal dust produced (Fabiano et al., 2014). Coal dust categorized as $PM_{2.5}$ and PM_{10} is even smaller than that of fine coal, measuring <3 mm (Faizal, Aprianti, et al., 2021; Faizal, Said, et al., 2021). Coal dust combines various heavy metals and toxic metals that harm human health due to long-term exposure. An inorganic multiplex mixture in coal dust consists of (C, H, O, N, Quartz, Cd, Fe, Br, Cu, Ni, Zn, Pb, Na, Ti, S, and Mg and their oxides, which vary according to particle size, type of and coal seams (Vasić et al., 2021).

In addition to domestic use, Indonesia imported coal to several countries through waterways (Pradono et al., 2019). Before shipping by ship, coal is stacked at the shipping station for a certain time before being loaded. As a result, coal dust that comes from the buildup at the station and during transportation by conveyor belts and waiting time for open coal transport vessels have exposed coal dust. So far, the coal dust highlighted is coal dust in coal mining and power generation units. Meanwhile, no attention was paid to the area around the coal unloading station in the waterway. To the best of our knowledge, no study has investigated coal dust characteristics and possible health effects of $PM_{2.5}$ and PM_{10} from coal unloading stations. This study aims to examine the characteristics of coal dust and its impact on the incidence of respiratory distress at the coal unloading station in Palembang. This work also examines the effect of climate parameters on the concentration of particulate matter.

Materials and methods

Coal dust was taken from a location adjacent to the coal unloading station on the banks of the Musi River, Palembang City, South Sumatra (3º01'02ºS, 104º44'55'E). Coal dust comes from coal stockpiles from three different companies, namely PT. A, PT. B and PT. C, hereinafter referred to as A, B, and C. Coal dust is carried by the wind to densely populated settlements across the river (3º01'01ºS, 104º44 '43'E). Coal dust was collected by manual grab sampling method at the sampling point using a scoop and then put into a plastic bag according to ISO 18283:2006. In detail, the research locations and sampling points are shown in Figure 1. The chemical analysis was carried out to determine the chemical composition of coal dust using X-ray Fluorescence Spectroscopy (PANalytical Epsilon 3 XLE XRF).

Figure 1. Study area of coal dust exposure

Results and discussion

Coal dust characteristics

The elemental composition of coal dust particulate matter collected in three sampling sites is summarized in Table 1. The elemental analysis of coal dust shows that silica has the highest concentration in the three places. Coal dust from PT. B has the largest number of sulfur-rich (S-rich) particles. Sulfate in PM2.5 is commonly identified as a secondary aerosol marker associated with long-distance transport (Cheng et al., 2018; Shah et al., 2020). The majority of sulfate particles have one or more potentially toxic metal inclusions. Fe is mainly found in dust from PT. C. Metals such as Fe can be associated with corrosion of equipment and vehicles. Several researchers have also identified dust, especially $PM_{2.5}$ and PM_{10}. The XRF technique has shown that airborne particulates mainly consist of S, Si, K, Al, Ca, Ti, and Fe, with Si, Al, S, and Fe as dominant elements (Cesari et al., 2016; Khodeir et al., 2012). Al and Si are mostly present in PM as mineral matter from coal dust, as presented by Gianoncelli et al. (2018). The levels of Al and Si present in coal dust are in the order PT A. > PT. B > PT. C. The content of Al and Si in PM also shows the contribution of road dust that is resuspended due to turbulence by moving vehicles and by wind (Gautam et al., 2016).

Table 1. Coal dust composition based on XRF analysis

Element	PT. A	PT. B	PT. C
Mg	0.150	2.196	3.077
Al	23.081	18.056	14.972
Si	46.325	34.203	24.518
P	2.822	5.634	10.160
S	11.652	13.621	9.247
K	1.822	1.382	0.824
Ca	3.761	8.970	15.984
Ti	1.341	1.484	1.642
Fe	7.761	11.629	15.391
Ag	0.825	2.010	2.608
Other	0.460	0.815	1.577

The PT. A SEM image (Figure 2a) shows that the coal network is covered with light and dark luminous material. This indicates the presence of mineral content in the form of irregularly shaped aggregates, where this bright light is due to the presence of calcium, aluminum, potassium, or sodium. In contrast, the light The dark part is primarily due to the presence of chalcophiles, the non-luminous part on the surface consists of carbon content (Yan et al., 2014). Chalcophile elements include Fe, S, and Ti (Kiseeva et al., 2017). Coal dust from PT. B (Figure 2b) has a smooth surface. Meanwhile, the SEM images of PT. C (Figure 2c) reveals several agglomerated small crystalline particles similar to PT. A.

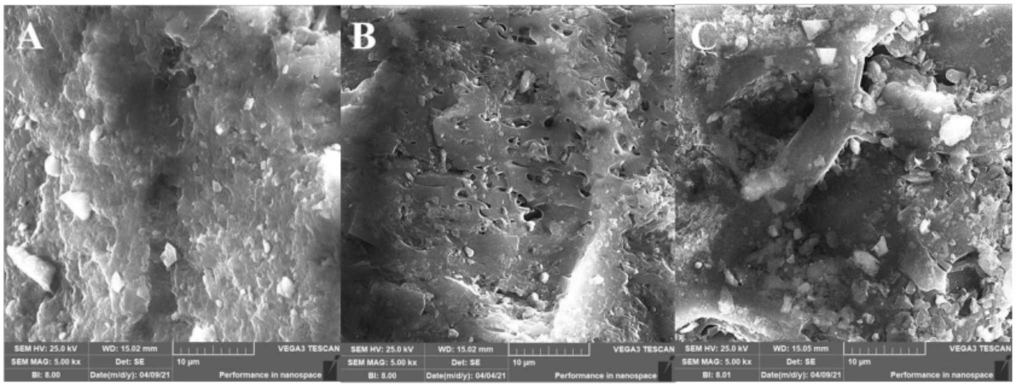

Figure 2. Coal morphology of the three coal companies

PM 2.5 and PM 10 analysis

The atmospheric pollutants in the air are $PM_{2.5}$ and PM_{10} (Guan et al., 2018). PM pollution affects air quality (Sun et al., 2019; Zhang & Gong, 2018) and even plays an essential role in global climate change (Pienkosz et al., 2019). PM at high concentrations can significantly increase the incidence of human respiratory and cardiovascular diseases and has the potential to cause death (Wu et al., 2019). Dust concentration measurement was carried out at 10 locations directly opposite the coal unloading station (Figure 3). Based on the results of a survey at ten observation points, it was found that there was a lot of coal dust stuck to the walls of residents' houses, and residents submitted complaints.

Figure 4 shows the results of measurements of $PM_{2.5}$ and PM_{10} concentrations at ten sampling points of areas exposed to coal dust. The content of $PM_{2.5}$ and PM_{10} was found to be highest at sampling points 6 and 7, which are directly opposite PT B and C. Meanwhile, the area directly opposite PT A also has a relatively high content of $PM_{2.5}$ and PM_{10}. However, all points show that $PM_{2.5}$ and PM_{10} are still within the regulatory threshold in Indonesia. Of the ten sampling points, points 6 and 7 have the highest concentrations for both $PM_{2.5}$ and PM_{10}. Although the $PM_{2.5}$ concentration is still below the 24-hour Indonesian national ambient air standard (65 g/m^3) (Kusuma et al., 2019), assuming that the sampling can represent the average annual $PM_{2.5}$ level, then the concentration will exceed the Indonesian annual average ambient air quality standard (15 g/m^3) and WHO guidelines (10 g/m^3) (Lestiani et al., 2015).

Exposure to $PM_{2.5}$ bound metals can cause carcinogenic severe or non-carcinogenic toxicity in humans depending on various factors such as exposure concentration, duration, and frequency. Industrial sources of $PM_{2.5}$ and PM_{10} are usually characterized by a strong contribution of Fe, as shown in Table 1. Dust-related sources are identified in the coarse fraction and are characterized by crustal elements, including Ca, Mg, Si, Al, Fe, and Ti. This source is generated locally from the distribution of coal from the delivery station to the temporary coal storage stockpile and loading to barges. Elements found in dust-related sources can also be associated with resuspended dust generated from coal transportation to shipping areas. Concentrations of Al, Si, S, and Fe are the main components. All of these components are probably emissions from coal.

Figure 3. Sampling point of measurement $PM_{2.5}$ and PM_{10}

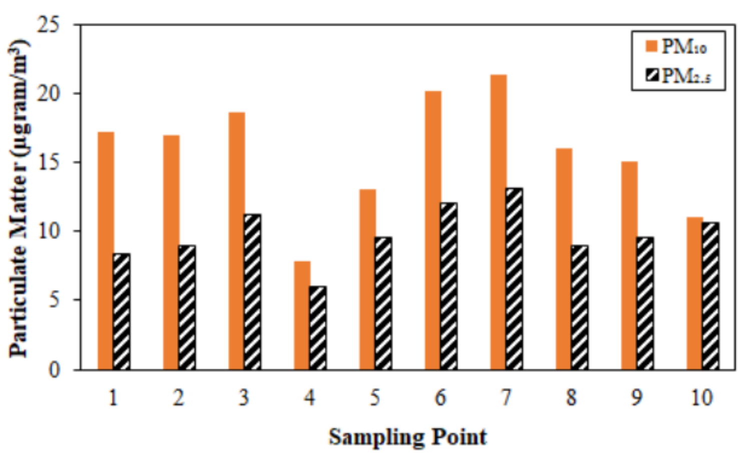

Figure 4. $PM_{2.5}$ and PM_{10} levels around coal unloading station

Effect of climate parameters on coal dust and PM concentration

The mass concentration of particulate matter (PM) is closely related to climate parameters, which will affect the diffusion of PM. Figures 5 – 7 show the average wind speed, temperature, and relative humidity at ten sampling points. The daily average wind speed is different at each point ranging from 3.53 to 5.20 m/s (Figure 5). The average daily temperature ranged from 28.7 to 32.4 °C (Figure 6), and the average relative humidity value varied from 68.4 to 73.1% (Figure 7). Spearman correlation was applied to identify the effect of climate parameters on particulate matter, the results of which are summarized in Table 2.

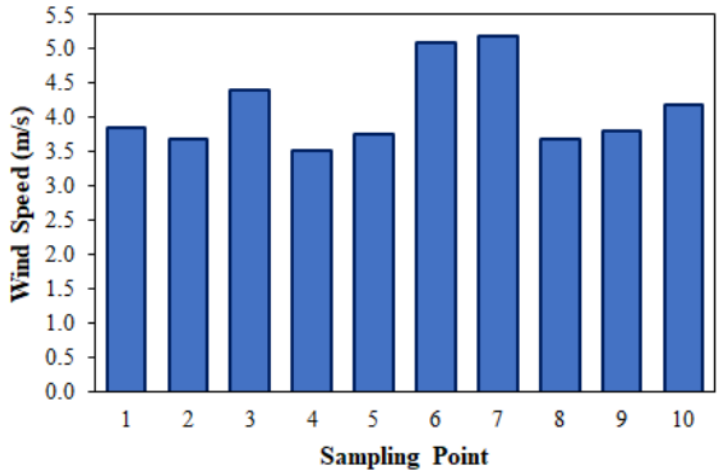

Figure 5. Average wind speed in sampling location around coal unloading station

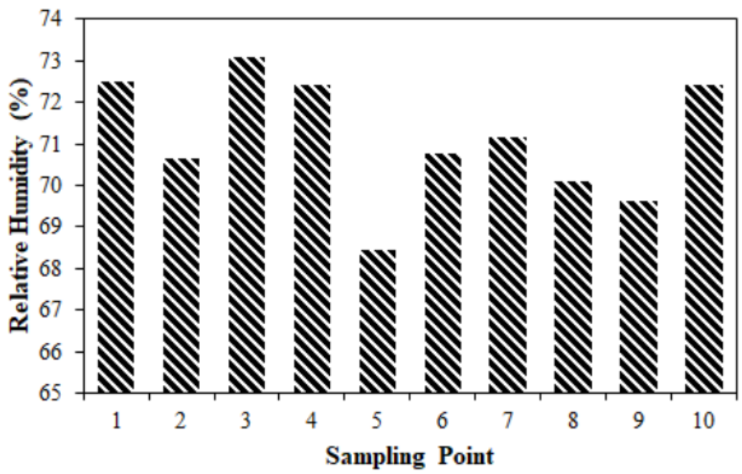

Figure 6. Average relative humidity in sampling location around coal unloading station

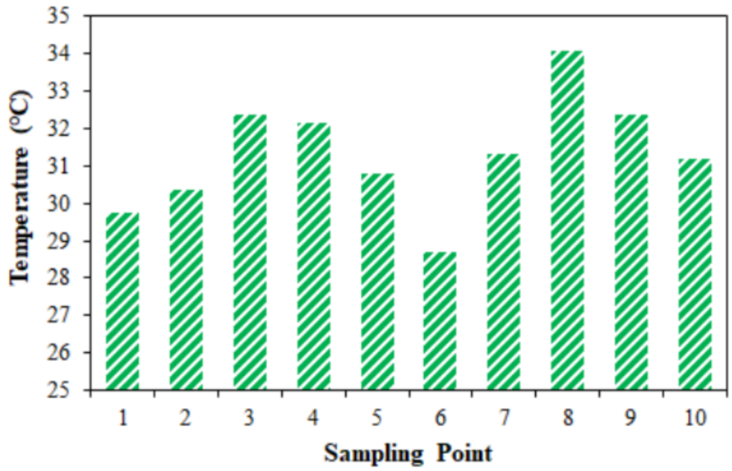

Figure 7. Average daily temperature in sampling location around coal unloading station

Table 2 shows the relationship between climate parameters and PM concentrations. Wind speed has a significant effect on $PM_{2.5}$ with p-value = 0.001 < 0.05. Wind speed and $PM_{2.5}$ have a very strong positive correlation with a correlation coefficient of 0.879. The same is also found in the PM_{10}. Wind speed has a significant effect on PM_{10} with p-value = 0.022 < 0.05. The two variables have a strong positive correlation with a correlation coefficient of 0.709. For every unit increase in wind speed, it will increase 0.879 $PM_{2.5}$ concentration and 0.709 PM_{10} concentration. Strong winds cause the rate of transfer of coal dust to increase. Temperature and relative humidity are negatively correlated to both $PM_{2.5}$ and PM_{10}. Every unit increase in temperature will decrease by 0.987 $PM_{2.5}$ concentration and 0.487 PM10 concentration. Furthermore, for every unit increase in relative humidity, it will decrease by 0.960 $PM_{2.5}$ concentration and 0.544 PM_{10} concentration.

Table 2. Correlation coefficient between $PM_{2.5}$ and PM_{10} concentrations and climate parameters

	Temperature	Relative humidity	Wind speed
$PM_{2.5}$	0.006	0.018	0.879^{**}
	p-value 0.987	p-value 0.960	p-value 0.001
PM_{10}	-0.249	0.219	0.709^{*}
	p-value 0.487	p-value 0.544	p-value 0.022

* means significance of $p < 0.05$; ** means significance of $p < 0.01$

Incidence of respiratory distress

There are two sub-districts directly opposite the coal station. The study continued by identifying the incidence of respiratory disease in children under five, which became a problem in the two districts. Figure 8 shows the total incidence of respiratory disorders in the last ten years compiled from two first-level health care facilities. Before the Covid-19 case (2012-2019), high cases of respiratory disorders were recorded in the two sub-districts. The highest number of cases reached 4576 patients in Makrayu sub-district. The incidence of respiratory disorders decreased when Covid-19 hit in 2020. This was made possible due to restrictions on people's movements, especially toddlers, because learning activities in schools are based online. Thus, the intensity of activities outside the home is much reduced.

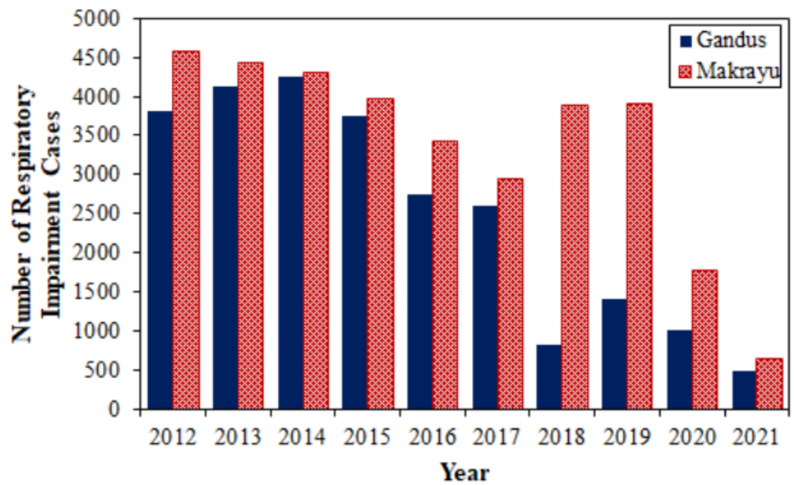

Figure 8. Incidence of respiratory disorders in children in Makrayu and Gandus (2012-2021)

Children are more active outdoors than adults, so they are more susceptible to exposure to polluted air. In addition, children have immune systems, and lung function is not fully developed. Environmental pollution that causes respiratory health problems in children is more significant, especially in developing countries, and this happens because it is accompanied by poor nutrition. Particulate matter from coal dust can cause decreased lung development in children, asthma, and lung and even heart disease (Liu et al., 2019).

Conclusion

Analysis of coal dust at the coal unloading station has been carried out. Coal dust is dominated by the elements Si, Al, S, and Fe. The concentrations of $PM_{2.5}$ and PM_{10} in the exposed coal dust are still below the daily threshold but have the potential to exceed the annual threshold. Wind speed has a significant effect on the spread of $PM_{2.5}$ and PM_{10}. There are cases of high respiratory distress that occur in toddlers in the coal dust distribution area.

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