Health risk analysis of heavy metal exposure bonded in $PM_{2.5}$ at industrial area in Bandung Regency

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Abstract. Heavy metal contents in $PM_{2.5}$ particulate dust poses potential risk to the health of human beings. This study aims to measure $PM_{2.5}$ dust concentrations and characterize heavy metals bound in $PM_{2.5}$ to estimate health risks in both children and adult groups. $PM_{2.5}$ dust was measured in Bandung Regency in industrial land uses, located in the Dayeuhkolot sub-district. Measurement of $PM_{2.5}$ concentrations using a Low Volume Air Sampler (LVAS) with PTFE filters. Sample was collected for 7 days x 24 hours. Heavy metals in $PM_{2.5}$ dust were characterized using ED-XRF. Calculation of non-carcinogenic and carcinogenic health risks was only performed on metals classified as Hazardous Air Pollutants (HAPs). The average concentration of $PM_{2.5}$ during the measurement period was 59,10±9,10 μg/m^3, exceeding the daily ambient air quality standard based on PP No.22 of 2021 which is> 55μg/m^3. The risk of non-carcinogenicity is expressed in Health Index (HI) values. The heavy metals considered in determining non-carcinogenic risk are As, Cd, Cr, Pb, Mn, Ni, Se, Fe, Zn, Si, and Sb as well as the crustal elements Si and Fe. Non-carcinogenic risk associated with exposure to heavy metals in $PM_{2.5}$ showed HI<1 for both children and adults. This indicates that the exposure to heavy metals in $PM_{2.5}$ around the Dayeuhkolot industrial area is at an acceptable risk level. HI value for heavy metal exposure for children was 0.34±0.17 and 0.42±0.28 for adults. In estimating the carcinogenic risk value, elements taken into account include As, Cd, Cr, Ni and Pb. Carcinogenic risk in both children and adults showed ECR>10^{-6} of 4.5×10^{-5} and 2.1×10^{-4}, respectively. This indicates that there is an unsafe health risk that can potentially cause carcinogenic effects in the population around the Dayeuhkolot industrial area The results of this study can be used as a reference database for establishing policies related to air quality in Bandung Regency.

1 Introduction

Recently, the increase in air pollution and its impact on humans and the environment has become a major concern around the world. [1]. $PM_{2.5}$ is one of the main air pollutant parameters that are monitored continuously. $PM_{2.5}$ dust is fine particles in the air with a size of 2.5 microns or smaller.

$PM_{2.5}$ dust can cause negative effects on human health, including respiratory tract disorders, infant health problems, circulatory disorders, and triggers for diabetes mellitus, and other chronic diseases. [2], [3]. Not only because of its size, which can cause health effects, but also because of $PM_{2.5}$'s ability to bind with various other toxic substances, such as heavy metals. Heavy metals bound to $PM_{2.5}$ levels such as Cr, Cd, As, Pb, and Ni, pose a serious risk to human health due to their persistent, accumulative, and environmentally damaging nature even at low concentrations. [4].

Heavy metals can be emitted into the atmospheric environment through both natural and anthropogenic activities, one of which is industrial activity [5]. According to Y.Han (2021), [6], 20,5 % of air pollution is generated from industrial processes, which makes industrial activities one of the sources of air pollution. Based on data Dinas Lingkungan Hidup dan Dinas Perindustrian Kab. Bandung (2023), [7], there are 15 large industries in the Dayeuhkolot sub-district. These industries are all engaged in the business of textile manufacturing processes, such as dyeing, spinning, knitting, weaving, and garments. The process of making textile materials generally utilizes heat energy. Heat energy is generated from the combustion process of fossil fuels. It is known that most of the large industries in the Bandung Regency area use coal as fuel [8]. Coal combustion is a possible contributor to $PM_{2.5}$ emissions in the Dayeuhkolot sub-district area. Heavy metals such as As and Cr contained in $PM_{2.5}$, are produced by coal burning, winter heating, and coal-dominated industrial emissions. In addition, metals such as Ni and V often share similar characteristics and are regarded as trace markers for heavy diesel burning in industrial emissions.

Other than because of the large number of industries in the Dayeuhkolot sub-district, data from the Bandung Regency Health Profile for 2018-2020, there are three diseases with the most cases based on outpatient data at

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the puskemas, namely non-acute respiratory tract infections (ISPA), acute nasopharynx, and hypertension. These three diseases can be caused and exacerbated by polluted air quality, especially $PM_{2.5}$ dust and heavy metals in $PM_{2.5}$.

Based on these considerations, this study was conducted to carry out a more in-depth community-based health risk analysis (HRA) and characterize heavy metals contained in $PM_{2.5}$ dust in the industrial area of Bandung Regency, specifically in Dayeuhkolot district. A health risk analysis was conducted to estimate the health risks posed by air pollution in the industrial area of Dayeuhkolot District, Bandung Regency. The results of this study are expected to be a reference for stakeholders to conduct comprehensive air quality management.

2 Methodology

2.1 Determination of $PM_{2.5}$ sampling locations

The sampling location is located in Bandung Regency which is in Dayeuhkolot subdistrict. The sampling location was chosen based on the dominant wind direction in Bandung Regency. The data used is historical data one year prior to sampling, this data was obtained from the BMKG Monitoring Station of Bandung City. In addition, the determination of sampling locations also considers the location of industries, which is based on data of industrial emission reports from the West Java Provincial Environment Office. The data were then processed and mapped using Google Earth Pro software to determine the sampling locations. The determination of this sampling location also refers to SNI 19-7119.6-2005 standard. Specifically, the sampling location is located in 6º59′37″s 107º32′27″E.

2.2 Determination of $PM_{2.5}$ concentration and characterization of heavy metals in $PM_{2.5}$

Air sampling using Low Volume Air Sampler (LVAS) Sibata brand C-20 series, and the filter used is PTFE filter. Air sampling was collected for 7 days x 24 hours. This air sampling refers to the SNI 7119.14-2016 standard. Meteorological parameters including air temperature, air pressure, air humidity, wind speed, and wind direction were also measured.

Gravimetric analysis was used to measure the mass of $PM_{2.5}$ by weighing the PTFE filter before and after sampling. The weighing difference is expressed as the mass of $PM_{2.5}$. Then the concentration is calculated based on the difference between the mass compared to the volume of air taken during the sampling period which has been converted into standard conditions. This analysis was done at Air Quality Laboratory Teknik Lingkungan Institut Teknologi Bandung. After gravimetric analysis, the filter samples were characterized for heavy metals using the ED-XRF instrument. by PANalytical at PT Cipta Mikro Material.

2.3 Community data collection

Community data collection aims to calculate the health risks for populations who may be potentially exposed to heavy metals in $PM_{2.5}$ dust at the sampling sites. Data collection is done by conducting interviews directly with respondents. The interview was carried out using a questionnaire to ask questions about age, gender, weight, height, residential history, history of health complaints, and activity patterns. The subjects of this study are people who meet the criteria, including having lived for at least 6 months in the area around $PM_{2.5}$ sampling, children aged 6-12 years, adults aged 25-55 years, and people who do not smoke. Data from these interviews are used to calculate exposure doses to calculate health risks.

The number of respondents who became the subject of this study was determined based on the formula developed by Issac and Michael, the formula is as follows [9]:

$$s = \frac{\lambda^2 \times N \times P \times Q}{d^2 \times (N-1) + \lambda^2 \times P \times Q} \quad (1)$$

Where S is the number of samples; λ^2 Chi Square with degree of freedom 1 and significance 5%; N is the total population; P is the probability of true (0.5); Q is the probability of false (0.5); d2 the difference between the sample mean and the population mean (0.1).

2.4 Health risk analysis (HRA)

A health risk analysis was performed based on the determination of $PM_{2.5}$ concentrations and heavy metals in $PM_{2.5}$ dust.

2.4.1 Exposure dose calculation

The exposure doses of $PM_{2.5}$ and heavy metals through the inhalation route were calculated using the following formula:

$$Intake = \frac{C \times R \times t_E \times f_E \times D_t}{W_b \times t_{avg}} \quad (2)$$

C : agent concentration (mg/m^3); R is inhalation rate (child : 0,5 m^3/hours; Adult: 0,83 m^3/hour); tE is time daily exposure (h/day), based on questionnaire; f_e exposure frequency (day/year); D_t is exposure duration (year); t_{avg} time average fon non-carcinogenic: Dt year x 365 day/year Effect carcinogenic : 70 year x 365 day/year = 25550 day.

2.4.2 Risk characterization

The calculation of risk characteristics is divided into two, which are non-carcinogenic and carcinogenic. Non-carcinogenic risk expressed with the notation HQ or Health Qotient is calculated by comparing the intake value of each agent with the reference dose (RfD), the calculation is as follows:

$$HQ = \frac{intake}{RfDInhalation} \tag{3}$$

If the HQ value <1, it can be said that the risk is safe, and if the HQ value> 1, the risk level is said to be unsafe.

To calculate the overall risk agent, the risk level is expressed by the Health Index (HI). HI is the aggregated value of the HQ value of each risk agent. If the HI value >1 then it is said to be unsafe. The formula is as follows:

$$HQ = \sum HI \tag{4}$$

The risk level for carcinogenic effects is expressed as an Excess Cancer Risk (ECR) notation which is the multiplication of the intake value with the cancer slope factor (CSF) value for each agent. To characterize the risk for carcinogenic effects, the following calculation is carried out:

$$ECR = I_c \times CSF \tag{5}$$

The risk level is acceptable or safe if ECR ≤ 10^{-6}, and otherwise if ECR> 10^{-6} then the risk level is unsafe.

3 Result and discussion

3.1 $PM_{2.5}$ concentration

Table. 1 shows the results of $PM_{2.5}$ measurements for 7x24 hours in the Dayeuhkolot industrial area. The average $PM_{2.5}$ concentration during the measurement period was 59,10±9,10 rg m^3. These concentrations exceed the ambient air quality standard regulated in PP No.22 of 2021, which is 55 rg/m^3. Based on $PM_{2.5}$ concentration parameters and health effects set by the United States Environmental Protection Agency (USEPA), $PM_{2.5}$ concentrations in the Dayeuhkolot industrial area are unhealthy [10]. However, to predict how much health risk due to $PM_{2.5}$ exposure, it will be specifically done by calculating the health risk analysis, and focused only on the heavy metal content of $PM_{2.5}$. High concentrations of $PM_{2.5}$ in this area can be explained by research conducted by [11], that industrial areas are the largest contributor to PM2.5 concentrations in the air after residential and agricultural areas.

Table 1. concentration of $PM_{2.5}$

Day of measurement	Concentration rg/m^3
1	40,29
2	61,88
3	64,90
4	61,00
5	55,76
6	67,98
7	61,86
Average	59,10
Standard deviation	9,10

Furthermore, $PM_{2.5}$ concentrations in an area can be affected by meteorological conditions, therefore multiple regression tests were also performed to determine the relationship of concentrations with meteorological factors. The results showed the influence of temperature, humidity, rainfall, wind direction and wind speed variables had a 100% effect on $PM_{2.5}$ concentrations. It was found that temperature and air velocity are postively correlated with $PM_{2.5}$ concentration, which means that if temperature and velocity increase, $PM_{2.5}$ concentration will increase. This result is similar to the results of research conducted by [12], which also found a positive correlation between temperature and $PM_{2.5}$ concentration, possibly because the number of days of measurement was small so that statistically it could not show a strong relationship.

This study was conducted during the wet season, where based on the humidity measurement results, the average humidity in this region reached 82%, or in high humidity conditions. Based on the results of the correlation analysis, humidity and rainfall are negatively correlated, which means that increasing humidity and rainfall will decrease $PM_{2.5}$ concentrations. High levels of humidity can cause particulates in the ambient air to aggregate together, causing the particulates cannot remain in the air and fall to the ground, which decreases $PM_{2.5}$ concentrations [13]. Meanwhile, rainfall can effectively remove particulate pollutants in the atmosphere through wet deposition mechanism [14].

3.2 Heavy metal characterization in $PM_{2.5}$ dust

Table.2 shows the results of heavy metal characterization in $PM_{2.5}$. There are 17 kinds of elements identified in $PM_{2.5}$ samples taken from Dayeuhkolot industrial area. Based on the concentrations of elements identified in $PM_{2.5}$ dust, it is known that Zn> Ti> Ag> S> Si> Fe> Mg> Ni> Sn> V> Sb> Cr> Pb> Hg> Cd> Se> As.

Table 2. Heavy metals chararterization in $PM_{2.5}$

Element	Concentration	24-hour average quality standard*
	ɼg/m^3	
Mg	0,524±0,67	120
Si	0,851±0,42	5
S	0,971±1,65	5
Ti	39,113±6,14	120
V	0,184±0,06	2
Cr	0,080±0,02	0,0003 5
Fe	0,547±0,41	5,00
Ni	0,233±0,06	2
Zn	40,094±10,5 4	120,00
As	0,002±0,00	0,3-2,5
Se	0,006±0,00	10
Cd	0,020±0,01	0,025
Sn	0,194±0,18	10
Sb	0,156±0,03	25
Hg	0,033±0,01	2
Pb	0,067±0,06	2
Ag	2,151±0,23	1

*Source :Ontario Ministry of the Environment, (2020)

If compared with the quality standards set by the Ontario Ministry of the Environment Ambient Air Quality Criteria (OAQC) only the element chromium exceeds the quality standard. In line with research conducted by [16] and [5] who conducted similar studies, showing that Cr metal is one of the metals that has the highest concentration in $PM_{2.5}$ dust.

According to [17] Cr can be found along with Mn and Fe as the main chemical components forming industrial emission footprints. In addition, according to [16] and [17], Cr metal is also found with other elements in coal dust, such as S, As, Hg, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Zr, Cd, Hg, and Pb. These elements are found abundantly in coal compared to average content of other crustal elements. This can be related to the characteristics of industries in the Dayeuhkolot Sub-district area, which are mostly engaged in textiles, such as dyeing, spinning, knitting, weaving, and garments. The textile manufacturing process generally utilizes heat energy. Heat energy is generated from the combustion of fossil fuels. It is known that most of the large industries in the Bandung Regency area use coal fuel [8].

Coal is one of the materials of the earth's crust, the footprint of coal combustion emissions can be characterized by other dominant elements in the ambient air of this region, such as Zn and Ti. Similar to the research conducted by [20], which also found Zn abundance in $PM_{2.5}$ samples, this element can be predicted as a marker of fossil fuel combustion. In addition, it is known that Ti is the most dominant element in PM2.5, reaching 50% of the total elements characterized [20]. Based on [17] and [19], Ti elements can come from soil dust or earth crust elemet. Therefore, coal burning is a possible contributor to $PM_{2.5}$ emissions in the Dayeuhkolot District area.

In addition, based on [22], the element Cr is one of the elements emitted by transportation activities both from motor vehicles and from road dust. Dayeuhkolot sub-district is a sub-district that has a high traffic density, this is also related to the high population density in this area. Population density affects environmental development and drives urban infrastructure development. Environmental development can increase community mobility patterns, as well as increase the frequency of transportation or traffic activities [23]. Therefore, it is estimated that the source of heavy metal emissions in ambient air in the Dayeuhkolot industrial area comes from transportation activities and also industrial emissions.

3.3 Health Risk Analysis (HRA) of non-carcinogenic heavy metal exposure

Noncarcinogenic risk characterization results of heavy metals are an aggregation of HQ values of each element expressed as HI values. The elements that are calculated for HQ values are elements that are categorized as HAP's such as As, Cd, Cr, Pb, Mn, Ni, Se, Fe, Zn, Si, and Sb as well as elements of the earth's crust, namely Si and Fe. HI value is an average of 120 respondents. Table.3 shows the results of HQ and HI calculations.

The results showed that the HI value <1 in both the children (0,34±0,17) and adult (0,42±0,28) groups. It can be interpreted that no non-carcinogenic health risks due to exposure to heavy metals in $PM_{2.5}$ in the Dayeuhkolot area for both children and adults.

If the risk associated with some similar research that has been done in industrial areas, such as in Thailand conducted by [24], in Iran conducted by [16], and in Indonesia at Cilegon city industrial estate conducted by [12] which showed a value of HI>1 or there is a non-carcinogenic health risk due to heavy metal exposure in the three industrial areas. This may be due to a number of samples not being representative of annual conditions. Furthermore, characteristics of industry types also influence the composition of airborne emissions. It is known that in this study the industrial area in Dayeuhkolt is dominated by the textile industry, in contrast to the characteristics of the type of industry in the Cilegon City industrial area which is dominated by the steel processing and petrochemical industries. In addition, the amount of heavy metals taken into account in determining HI also determines the magnitude of the HI value.

Table 3. HRA non-carcinogenic

Element	RfD	HQ	
		Child	Adult
As	1,2Ч10^{-4}	1,4Ч10^{-3}	1,1Ч10^{-3}
Cd	1,0Ч10^{-3}	1,7Ч10^{-3}	1,4Ч10^{-3}
Cr	2,8Ч10^{-5}	2,6Ч10^{-1}	2,1Ч10^{-1}
Pb	3,5Ч10^{-4}	1,6Ч10^{-2}	1,3Ч10^{-2}
Ni	2,1Ч10^{-2}	9,7Ч10^{-4}	8,0Ч10^{-4}
Se	5,0Ч10^{-3}	1,0Ч10^{-4}	8,5Ч10^{-5}
Fe	7,0Ч10^{-1}	6,7Ч10^{-5}	5,5Ч10^{-5}
Zn	3,0Ч10^{-1}	1,1Ч10^{-2}	9,4Ч10^{-3}
Si	5,0Ч10^{-3}	1,5Ч10^{-2}	1,2Ч10^{-2}
Sb	4,0Ч10^{-4}	3,3Ч10^{-2}	2,7Ч10^{-2}
HI		**0,34**	**0,28**
Std. deviation		**0,17**	**0,28**

The results of this risk estimate can also relate to the prevalence data of pneumonia, which was obtained from the Health Department of Bandung Regency in 2018. Pneumonia is one of the diseases that can be caused and exacerbated by air pollution[25]. Based on the data obtained, Dayeuhkolot Sub-district is one of the areas in Bandung Regency that has a low prevalence of pneumonia compared to other areas. The low prevalence of pneumonia in this area is in line with non-carcinogenic health risk estimates in this region as shown by the HI<1 value. Accordingly, this condition can represent the actual condition of public health in the Dayeuhkolot industrial area.Then to review factors that influence community health risks, a Chi-square bivariate analysis was conducted. .. Factors included in the analysis included age, gender, symptoms of health problems, smoking/passive smoking habits, distance of the house from the highway, and indoor pollution exposure, these data are collected from interviews. The results of this association analysis were divided into child and adult groups.

According to the results of the bivariate chi-square test for children and adults, the non-carcinogenic risk of heavy metal exposure in children and adults is influenced by the respondents home distance to the highway ($p = 0.004$). While other factors do not affect the risk of non-carcinogenic heavy metals.

Distance from the house to the roadway is associated with the level of non-carcinogenic risk of exposure to heavy metals in $PM_{2.5}$. This is in line with [26], that emissions from industrial activities and motor vehicle emissions are considered one of the main sources of heavy metal contamination in the environment, especially in urban areas with high traffic flow. Heavy metals from road dust can be generated from automobile emissions, road scraping, tires, and brakes and can also be accumulated in road dust through precipitation in dry or wet atmospheres. Therefore, people who use who live near the roadway are potentially exposed to heavy metals through inhalation greater than those who live away from the roadway.

3.4 Health Risk Analysis (HRA) of carcinogenic heavy metal exposure

Heavy metals that are taken into account to determine carcinogenic risk are As, Cd, Cr, Pb and Ni. These metals are listed by the International Agency for Research on Cancer (IARC) as metals that can case carcinogenic effects.

Tabel 4. shows the average aggregated ECR values of five heavy metals in a total of 120 respondents, both children and adults. The results show ECR >10^{-6}, children (4,5Ч10^{-5}) and adults (2,1Ч10^{-4}) in study areas. This indicates that all respondents, both children and adults, in study area have a potentially unsafe health risk of carcinogenic health effects.

Table 4. HRA carcinogenic

Element	SF	ECR	
		Child	Adult
As	0,0043	9,9Ч10^{-11}	2,0Ч10^{-10}
Cd	6,3	1,5Ч10^{-6}	3,0Ч10^{-6}
Cr	42	4,1Ч10^{-5}	8,4Ч10^{-5}
Pb	0,00042	3,3Ч10^{-10}	6,6Ч10^{-10}
Ni	0,84	2,3Ч10^{-6}	4,6Ч10^{-6}
ECR		4,5Ч10^{-5}	2,1Ч10^{-4}

ECR values of each metal Cr> Ni> Cd> Pb> As. Chromium has the highest risk value and exceeds the acceptable level. Similar to the results of research conducted by [27] which also showed that the ECR of Cr metal exceeded the acceptable level. According to [6] heavy metals such as As and Cr contained in $PM_{2.5}$, are produced by coal burning, coal-dominated industrial emissions.

Due to the long-term health risks (risk of carcinogenic disease) in the community in the Dayeuhkolot industrial area, it is necessary to continuously monitor air quality in this area by installing an air quality monitoring station. In addition, risk management measures need to be taken to reduce the risk of community health problems in this area.

4 Conclusion

The average concentration of $PM_{2.5}$ dust at Dyeuhkolot industrial area in Bandung Regency is 59.10±9.10 rg/ m^3. Non carcinogenic risk associated with exposure to heavy metals in $PM_{2.5}$ showed HI<1 for both children and adults, that is 0.34±0.17 for children and 0.42±0.28 for adults. It indicates that the exposure to heavy metals in $PM_{2.5}$ around the Dayeuhkolot Industrial area is at an acceptable risk level. Carcinogenic risk in both children and adults showed ECR>10^{-6} , which is 4.5Ч10^{-5} and 2.1Ч10^{-4}, respectively. This indicates that there is an unsafe health risk that can potentially cause carcinogenic effects in the population around the Dayeuhkolot industrial area.

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References

[1] S. Maji, S. Ahmed, M. Kaur-Sidhu, S. Mor, and K. Ravindra, "Health Risks of Major Air Pollutants, their Drivers and Mitigation Strategies: A Review," *Air, Soil and Water Research*, vol. 16, p. 117862212311546, Jan. 2023, doi: 10.1177/11786221231154659.

[2] S. Feng, D. Gao, F. Liao, F. Zhou, and X. Wang, "The health effects of ambient PM2.5 and potential mechanisms," *Ecotoxicology and Environmental Safety*, vol. 128, pp. 67–74, Jun. 2016, doi: 10.1016/j.ecoenv.2016.01.030.

[3] R. B. Schlesinger, N. Kunzli, G. M. Hidy, T. Gotschi, and M. Jerrett, "The Health Relevance of Ambient Particulate Matter Characteristics: Coherence of Toxicological and Epidemiological Inferences," *Inhalation Toxicology*, vol. 18, no. 2, pp. 95–125, Jan. 2006, doi: 10.1080/08958370500306016.

[4] U. S. E. P. A. US EPA, "Overview of Airborne Metals Regulations, Exposure Limits, Health Effects, and Contemporary Research." Accessed: Jun. 08, 2023. [Online]. Available: https://www3.epa.gov/ttnemc01/prelim/otm31appC.pdf

[5] M. Soleimani, N. Amini, B. Sadeghian, D. Wang, and L. Fang, "Heavy metals and their source identification in particulate matter (PM2.5) in Isfahan City, Iran," *Journal of Environmental Sciences*, vol. 72, pp. 166–175, Oct. 2018, doi: 10.1016/j.jes.2018.01.002.

[6] Y. Han *et al.*, "PM2.5-Bound Heavy Metals in Southwestern China: Characterization, Sources, and Health Risks," *Atmosphere*, vol. 12, no. 7, p. 929, Jul. 2021, doi: 10.3390/atmos12070929.

[7] Dinas Lingkungan Hidup dan Dinas Perindustrian Kab. Bandung, "20190207061125-database-industri-skala-besar-kabupaten-bandung.pdf." Accessed: Jul. 14, 2023. [Online]. Available: https://www.bandungkab.go.id/uploads/20190207061125-database-industri-skala-besar-kabupaten-bandung.pdf

[8] R. Ningsih, "69 Perusahaan Tekstil Beralih ke Batubara." Accessed: Jul. 14, 2023. [Online]. Available: https://digilib.polban.ac.id/gdl.php?mod=browse&op=read&id=jbptppolban-gdl-clipp-2006-rahayuning-1093

[9] Sugiyono, *Statistika untuk Penelitian*. Bandung: ALFABETA, 2021.

[10] US EPA, "Particle Pollution and Your Health," 2022.

[11] Y. Li *et al.*, "Exploring the contributions of major emission sources to PM2.5 and attributable health burdens in China," *Environmental Pollution*, vol. 322, p. 121177, Apr. 2023, doi: 10.1016/j.envpol.2023.121177.

[12] T. Mulyani, "ANALISIS RISIKO KESEHATAN LOGAM BERAT DAN SILIKA DALAM DEBU PM2.5 PADA MASYARAKAT SEKITAR KAWASAN INDUSTRI DI CILEGON," Institut Teknologi Bandung, Bandung, 2021.

[13] Q. Dong, P.-S. Zhao, and Y.-N. Chen, "[Impact of Collision Removal of Rainfall on Aerosol Particles of Different Sizes]," *Huan Jing Ke Xue*, vol. 37, no. 10, pp. 3686–3692, Oct. 2016, doi: 10.13227/j.hjkx.2016.10.002.

[14] Y. Wang and L. He, "Effect of rainfall intensity on PM $_{10}$ and PM $_{2.5}$ scavenging in Guangzhou at night," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 450, no. 1, p. 012075, Feb. 2020, doi: 10.1088/1755-1315/450/1/012075.

[15] Ontario Ministry of the Environment, "AMBIENT AIR QUALITY CRITERIA." Toronto, Canada, 2020.

[16] M. Kermani *et al.*, "Concentration, sources and bioaccessibility-based risk assessment of heavy metals in air-borne PM2.5 in different landuses of Tehran," *International Journal of Environmental Science and Technology*, vol. 19, no. 7, pp. 6691–6704, Jul. 2022, doi: 10.1007/s13762-021-03865-3.

[17] S. Bie *et al.*, "Source appointment of PM2.5 in Qingdao Port, East of China," *Science of The Total Environment*, vol. 755, p. 142456, Feb. 2021, doi: 10.1016/j.scitotenv.2020.142456.

[18] A. Altıkulaç *et al.*, "Assessment of the Enrichment of Heavy Metals in Coal and Its Combustion Residues," *ACS Omega*, vol. 7, no. 24, pp. 21239–21245, Jun. 2022, doi: 10.1021/acsomega.2c02308.

[19] V. Bangar, A. K. Mishra, M. Jangid, and P. Rajput, "Elemental Characteristics and Source-Apportionment of PM2.5 During the Post-monsoon Season in Delhi, India," *Frontiers in Sustainable Cities*, vol. 3, 2021, Accessed: Sep. 14, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/frsc.2021.648551

[20] S. R. Won *et al.*, "PM2.5 and Trace Elements in Underground Shopping Districts in the Seoul Metropolitan Area, Korea," *IJERPH*, vol. 18, no. 1, p. 297, Jan. 2021, doi: 10.3390/ijerph18010297.
[21] G. Rincon *et al.*, "PM2.5 exceedances and source appointment as inputs for an early warning system," *Environmental Geochemistry and Health*, vol. 44, no. 12, pp. 4569–4593, Dec. 2022, doi: 10.1007/s10653-021-01189-2.
[22] K. Liu, Q. Shang, C. Wan, P. Song, C. Ma, and L. Cao, "Characteristics and Sources of Heavy Metals in PM2.5 during a Typical Haze Episode in Rural and Urban Areas in Taiyuan, China," *Atmosphere*, vol. 9, no. 1, p. 2, Dec. 2017, doi: 10.3390/atmos9010002.
[23] C. Lee, "Impacts of multi-scale urban form on PM2.5 concentrations using continuous surface estimates with high-resolution in U.S. metropolitan areas," *Landscape and Urban Planning*, vol. 204, p. 103935, Dec. 2020, doi: 10.1016/j.landurbplan.2020.103935.
[24] P. Sakunkoo *et al.*, "Human health risk assessment of PM2.5-bound heavy metal of anthropogenic sources in the Khon Kaen Province of Northeast Thailand," *Heliyon*, vol. 8, no. 6, p. e09572, Jun. 2022, doi: 10.1016/j.heliyon.2022.e09572.
[25] X. Zhou *et al.*, "Associations between air pollutant and pneumonia and asthma requiring hospitalization among children aged under 5 years in Ningbo, 2015–2017," *Front. Public Health*, vol. 10, p. 1017105, Jan. 2023, doi: 10.3389/fpubh.2022.1017105.
[26] T. T. T. Duong and B.-K. Lee, "Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics," *Journal of Environmental Management*, vol. 92, no. 3, pp. 554–562, Mar. 2011, doi: 10.1016/j.jenvman.2010.09.010.
[27] Y. Li *et al.*, "Characteristics, sources and health risk assessment of toxic heavy metals in PM2.5 at a megacity of southwest China," *Environ Geochem Health*, vol. 38, no. 2, pp. 353–362, Apr. 2016, doi: 10.1007/s10653-015-9722-z.