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Environmental health risk analysis due to PM₁₀ during 2015's smoke haze pollution in Sawahlunto City

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Abstract. This research was aimed to analyze metal concentrations in particulate matter 10 (PM₁₀) sampled from ambient air in Sawahlunto City during the occurrence of smoke-haze pollution in 2015. The metal contents comprise of Al, Cr, Mn, Co, Ni, and Cd, which represented the potential for both non-carcinogenic and carcinogenic illnesses. The obtained metal concentrations were further used to estimate health risk on human by using environmental health risk assessment approach. PM₁₀ samplings were done by using Minivol Air Sampler while the metal concentration analysis was conducted by atomic absorption spectrophotometer after PM₁₀ filter destruction. It was found out that during the smoke-haze pollution the PM₁₀ concentrations were above Indonesian air quality standard and considered at hazardous level in accordance to the Indonesian air quality index. The results of environmental health risk assessment for children and adults show the Hazard Quotient (HQ) value > 1 for non-carcinogenic metals (Al, Cr, Mn). As for the carcinogenic metals (Co, Ni, Cd), it was estimated that the Excess Lifetime Cancer Risk (ELCR) > 10⁻⁶ for both children and adults. It can be concluded that the occurrence of smoke-haze pollution in Sawahlunto City in 2015 increased the risk of cancer illnesses in both children and adults due to the high metal concentrations in PM₁₀.

1. Introduction

A forest fire is a phenomenon that often occurs in Indonesia [1] which is a local and global concern [2]. Forest fires are not new in Indonesia, in Sumatra and Kalimantan forest fires have occurred since the 17th century [3]. This forest/land fire causes haze, in either small or large scales. The emergence of haze due to a forest and/or land fires on a large scale has very large and detrimental multi-dimensional impacts. One of these impacts can be felt from the significant degradation of air quality, which results in a decrease in the level of comfort and health for people who experience haze. Not only that, referring to the nature of moving in the circulation of air masses or wind movements, the spread of smoke haze is a trans boundary event. In other words, the haze emitted from one place, supported by possible conditions, can disperse to other places. This has led to a wide range of areas affected by haze [4].



Since the end of August 2015, the provinces of Riau, Jambi, South Sumatra, and West Sumatra have been shrouded in haze due to forest/land fires, especially in areas with extensive peat land and plantation coverage. This condition continued for several weeks, and the impact of this haze caused a decrease in visibility that disrupted flight activities and economic activity in the region. Smoke haze also caused a decrease in air quality in the cities of the province to reach dangerous levels. Indications of this condition are seen from the concentration level of several air quality parameters, one of which is the Particulate Matter 10 (PM₁₀) aerosol concentration [5]. PM₁₀ is a particle or dust that is in the air and has a size of not more than 10 µm (micrometer) or one-hundredth of a millimeter and is an important part of smog for short-term (an hour or weekly) exposure. The particulate material is suspended particles, which are a mixture of solid particles and liquid droplets. The potential effects of particulate matter on health depend on the source, season, and weather conditions [5].

Sawahlunto City is astronomically located at 0° 34' - 0° 46' South Latitude and 100° 41' - 100° 49' East Longitude. Topographically the area of Sawahlunto City is located in hilly areas with an altitude between ± 250 - 650 meters above sea level. This region stretches from North to South, East and South parts have relatively steep topography (slope of more than 40%) which covers 28.52% of the total area [6]. This condition causes Sawahlunto City to be one of the rain shadow areas which cause air pollutants to be trapped because they cannot be dispersed horizontally and result in longer polluting material residence time in this area compared to areas that have relatively flat topography.

This research was aimed to analyze the concentration of metals in PM₁₀ due to smoke haze and estimates of risks to health, both for children and adults. This research was conducted because in a previous study [7] on the analysis of metal content in filters due to forest fires in Kalimantan showed that some metal contents were considered as potentially harmful to health.

2. Materials and Methods

2.1. Time and Location of Research

This research was carried out during the haze period, October 22-28, 2015 and under normal conditions (without smoke haze), which was 4-5 March 2016. This study included the collection of secondary data in the form of a population, administrative conditions, topography, rainfall, and PM₁₀ filter measurements made by the Environmental Agency Office (BLH) of Sawahlunto City during the smoke haze occurrence. Ambient air particulate samplings were done at the BLH Office and Puncak Cemara (as background concentration) of Sawahlunto City. Furthermore, the filters used in the measurement when the smoke hazes and without the smoke haze were analyzed for the metal contents in the Water Quality Laboratory of the Environmental Engineering Department, Universitas Andalas. The location of particulate sampling is shown in Figure 1 and Windrose During Sampling Period is shown in Figure 2.

2.2. PM₁₀ measurement

PM₁₀ sampling was conducted by using Minivol Air Sampler. The Minivol Air Sampler is a standard tool used to determine or measure the concentration of suspended particles in the ambient air by gravimetric method. PM₁₀ air flow rate was 5 L / min. PM₁₀ sampling was carried out for 24 hours at each sampling point. The filter used for measuring PM₁₀ was stored in a desiccator for 24 hours. The filter was then weighed 5 times to get the initial weight (W₀). During sampling, every 15 minutes of meteorological conditions including temperature, temperature, wind speed, wind direction, and air pressure were recorded for 24 hours of measurement. The finished filter was put into the desiccator for 24 hours before being weighed again to get the final weight (W_t). The following are the stages of determining PM₁₀ concentration: (1) Calculating the volume of sampled ambient air using following formula:

$$V = \frac{(Q_1 + Q_2 + \dots + Q_n) \times t}{n} \tag{1}$$

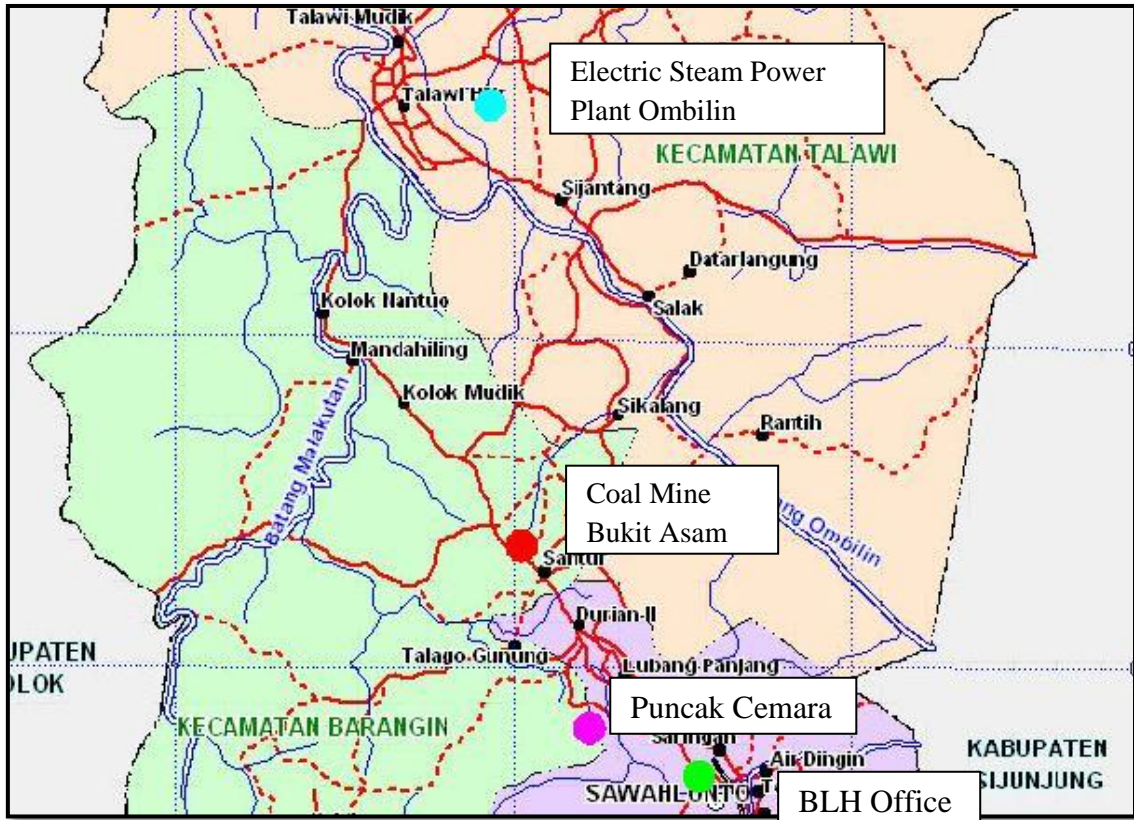


Figure 1. Location of study

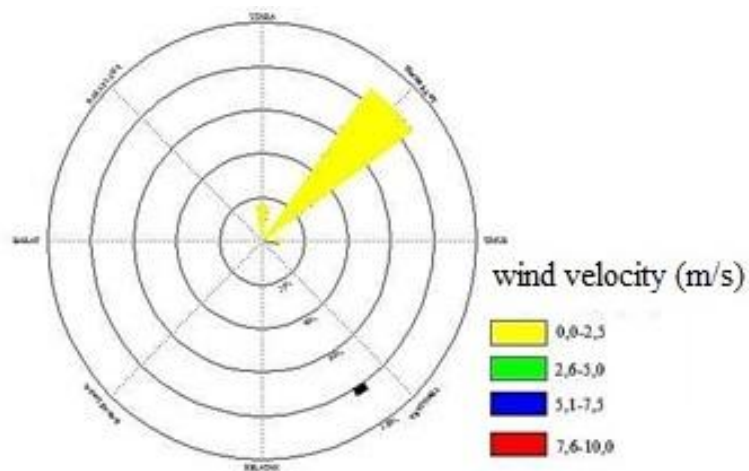


Figure 2. Windrose During Sampling Period

Where V is the volume of air sampled (m^3), Q is the air flow rate ($m^3/minute$), and n is the amount of recording data (2) Calculating the standard gas volume using formula:

$$V_{stp} = \frac{P_s \times V_s \times T_{stp}}{T_s \times P_{stp}} \quad (2)$$

Where V_s is the volume of air (m^3), P_s is air pressure (mmHg), T_s is air temperature (K), V_{stp} is the volume of sampled ambient air after being corrected to standard air at 273 K and 1 atm, T_{stp} is a standard temperature of 273 K, and P_{stp} is the air pressure in the standard state of 1 atm or 760 mmHg (3) the calculation of PM_{10} concentration using the equation:

$$C = \frac{(W_t - W_o) \times 10^6}{V_{stp}} \quad (3)$$

Where C is the concentration of PM_{10} ($\mu g/m^3$), W_o is the initial weight of the filter (g), W_t is the final weight of the filter (g).

2.3. Analysis of Metal Concentration (Al, Cr, Mn, Co, Ni, Cd)

The metal elements found in PM_{10} (Al, Cr, Mn, Co, Ni, and Cd) were analyzed in the Water Laboratory of the Environmental Engineering Department using the Atomic Absorption Spectrophotometer (AAS) equipment. This equipment is able to detect metal content in a solution with a certain wavelength. Readings on this tool require particulate samples to be in liquid form. In this case to dilute the particulates that have accumulated in the filter is done by the filter destruction method. The destruction process is carried out in a fume hood because it uses an irritant HNO_3 solution. LoD (Limit of Detection) of the AAS for each metal parameter was 0.001 ppm.

2.4. Environmental Health Risk Assessment (EHRA)

The public health risk is calculated using the Environmental Health Risk Assessment (EHRA) method. EHRA is a process intended to calculate or estimate risks to human health due to certain agents [8]. Agents in this study are metals in PM_{10} which are non-carcinogens (Al, Cr, Mn) and carcinogens (Co, Ni, Cd). The following are steps in estimating public health risks using the EHRA method: (1) Identification of hazards (identifying metals that are harmful to health by dividing into two categories, namely metals that are non-carcinogens and carcinogens); (2) Analysis of exposure by calculating the value of the Chronic Daily Intake (CDI) with the following equation [8]:

$$CDI (mg/kg.day) = \frac{\text{Total dose (TD, } mg/m^3) \times \text{Inhalation rate (IR, } m^3/hari)}{\text{Body weight (BW, kg)}} \quad (4)$$

$$TD = C \times E \quad (5)$$

Where C is the concentration of metal in PM_{10} and E is the deposition of PM_{10} calculated by the following equation[8]:

$$E = -0.081 + 0.23 \ln(Dp)^2 + 0.23 \sqrt{Dp} \quad (6)$$

DP is the diameter of the particulate which is 10 μ m. The inhalation rate for adults is 20 m³/day with an average body weight of 55 kg and the inhalation rate of children is 12 m³/day with an average weight of 15 kg [8]; (3) Dose-response analysis that is looking for the Reference of Dose (RfD), Reference of Concentration (RfC), Slope Factor (SF) of the risk agent. The values of RfD, RfC, and SF for each metal can be found at www.epa.gov/iris; (4) risk characterization is calculated based on exposure analysis and dose-response analysis.

For non-carcinogenic metals, the risk characteristics are stated in the notation of Hazard Quotient (HQ) [8]

$$HQ = CDI / RfD. \quad (7)$$

For metal carcinogens expressed in excess lifetime cancer (ELCR) with the equation [8]:

$$ELCR = CDI \times SF \quad (8)$$

3. Results and Discussions

3.1. PM₁₀ concentration

PM₁₀ concentration during the occurrence of smoke haze was 708 μ g/m³, while the lowest concentration was 472 μ g/m³, and the average concentration was 581.24 μ g/m³. Whereas during normal conditions (without smoke haze), the measured pollutant concentrations were only 57.09 μ g/m³ and 23.55 μ g/m³ (background concentration). Table 1 is showing the concentration of PM₁₀ in Ambient Air.

Table 1 PM₁₀ Concentrations in ambient air

No.	Sampling Date	Sampling Location	PM ₁₀ (μ g/m ³)	Standard (μ g/m ³)	Status
1	22 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	583.30	150	Smoke Haze
2	23 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	569.40	150	Smoke Haze
3	24 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	708.00	150	Smoke Haze
4	25 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	652.00	150	Smoke Haze
5	26 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	472.00	150	Smoke Haze
6	27 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	528.00	150	Smoke Haze

7	28 Oct'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	556.00	150	Smoke Haze
8	04 Mar'15	BLH Office (0°40'38.1"S 100°46'38.5"E)	57.09	150	Normal
9	05 Mar'15	Puncak Cemara (0°40'26.3"S 100°46'25.3"E)	23.55	150	Normal

PM₁₀ concentration is directly proportional to the number of hotspots on the island of Sumatra. The highest PM₁₀ concentration happened when the number of hotspots on Sumatra Island was the highest too. Following is a graph that shows the number of hotspots in Sumatra Island during the period of smoke haze on October 22-28 2015.

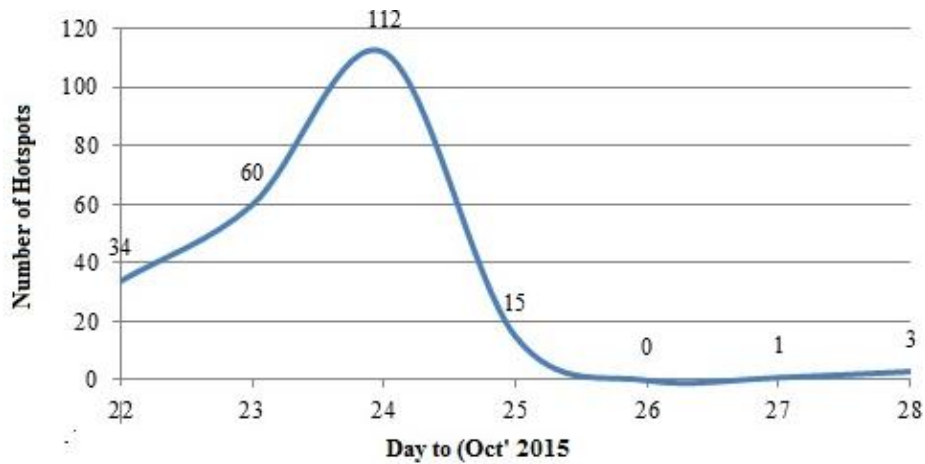


Figure 3. The Number of Hotspots on Sumatra Island

3.2. The Concentration of Metals in PM₁₀

The highest concentration of metals in PM₁₀ was on October 24, 2015, when the concentration of PM₁₀ was also high. While on October 26, 2015, the concentration of metals was at the lowest level where the concentration of PM₁₀ on this date was also the lowest. The average concentrations of metals Al, Cr, Mn, Co, Ni, and Cd are as follows 3,991; 3,929; 2,908; 2,386; 4,682, and 2,279 µg / m³. Table 2 is shown metal concentrations in PM₁₀ on and without smoke haze conditions.

Table 2. Metal concentrations in PM₁₀

Smoke Haze						
Sampling Date	Concentration (µg/m³)					
	Al	Cr	Mn	Co	Ni	Cd
22 Oct'15	4.517	4.198	3.272	2.664	4.951	2.606
23 Oct'15	4.053	4.053	2.895	2.316	4.864	2.085
24 Oct'15	5.182	4.951	3.764	3.011	5.356	3.243
25 Oct'15	4.661	4.430	3.329	2.895	5.067	2.866
26 Oct'15	2.866	2.721	2.027	1.679	3.851	1.477
27 Oct'15	3.069	3.532	2.345	1.911	4.140	1.708
28 Oct'15	3.590	3.619	2.721	2.229	4.545	1.969
Mean	3.991	3.929	2.908	2.386	4.682	2.279
Normal						
04 Mar'15	0.579	0.232	0.492	0.347	0.463	0.637
Background						
05 Mar'15	0.376	0.145	0.261	0.261	0.261	0.318

3.3. EHRA

After the metal concentration in PM₁₀ is obtained, then the data is used to estimate the risk to public health in Sawahlunto City. The concentration of metals used is the average concentration in Table 2. From Table 2, the calculation of the public health risks in Sawahlunto City is divided into 2 categories, namely children and adults. The following are the health risks that will arise due to exposure to non-carcinogenic metals and carcinogens for children and adults in Tables 3 and 4 and Table 5 regarding the risk ratio of children with adults.

Table 3. EHRA for children

Metals	C (mg/m³)	CDI (mg/kg.hari)	RFC	SF	HQ	ELCR
Al	0.0040	0.00546	0.0014		3.90	
Cr	0.0039	0.00538	0.000029		185.35	
Mn	0.0029	0.00398	0.000014		284.11	
Co	0.0024	0.00326		32		0.104470

Ni	0.0047	0.00640	0.84	0.005380
Cd	0.0023	0.00312	6.3	0.019641
Total			473.36	0.129491

Table 4. EHRA for adults

Metals	C (mg/m ³)	CDI (mg/kg.day)	RFC	SF	HQ	ELCR
Al	0.0040	0.00248	0.0014		1.77	
Cr	0.0039	0.00244	0.000029		84.25	
Mn	0.0029	0.00181	0.000014		129.14	
Co	0.0024	0.00148		32		0.047486
Ni	0.0047	0.00291		0.84		0.002446
Cd	0.0023	0.00142		6.3		0.008928
Total					215.16	0.058859

Table 5. Risk Ratios of children to adults from metal concentrations in PM₁₀

HQ		Ratio	ELCR		Ratio
Children	Adults		Children	Adults	
3.90	1.77	2.20	0.104470	0.047486	2.20
185.35	84.25	2.20	0.005380	0.002446	2.20
284.11	129.14	2.20	0.019641	0.008928	2.20

From Table 3 it is known that the hazard level of non-carcinogenic metals (total HQ) > 1, i.e., 473.36. While the hazard level of metal carcinogen (total ELCR) is 129.49x10⁻³. These data indicate that the non-carcinogen and carcinogen metals in PM₁₀ are not safe for the health of children in the city of Sawahlunto, since the safe limit for the values of HQ ≤ 1 and ELCR ≤ 10⁻⁶. The obtained value of the ELCR indicates that there will be 129 to 130 of the total of 1,000 children in Sawahlunto City expected to receive cancer effects due to exposure to metals in PM₁₀ during the smoke haze pollution. Furthermore, from Table 4, the HQ value for adults is 215.16 or HQ > 1 and the ELCR value for adults is 58.85 x10⁻³ where the ELCR value is > 10⁻⁶ which is a safe limit for metal carcinogens. The value of the ELCR indicates that there will be 58 to 59 of 1,000 adults who will get cancer in the City of Sawahlunto. As for the non-carcinogenic metals, we can see the risk ratios from Table 5 that will be received by children and adults due to exposure to those metal concentrations and PM₁₀ carcinogens in

Sawahlunto City. It can be seen that the risk to children is 2.2 times higher than that of adults. This is caused by lighter children's than that of adults. The reason is because the intake value is influenced by the concentration value of the risk agent, the rate of intake, and weight of a person [9].

4. Conclusion

Smoke haze caused by forest fires that occurred in Indonesia, especially in the island of Sumatra has increased PM₁₀ concentration in the ambient air of Sawahlunto City. This PM₁₀ concentration has exceeded the quality standards set by the Government of Indonesia through PP RI 41/1999. The smoke haze caused by forest and land fires also contains several metals that are harmful to health such as Al, Cr, Mn, Co, Ni, and Cd. These metals concentration increased many times in the ambient air during the occurrence of smoke haze pollution and are directly proportional to PM₁₀ concentrations. Environmental health risk assessment for both children and adults in Sawahlunto City which has been calculated using the concentration of the six metals indicates that there will be 129 to 130 of 1,000 children and 58 to 59 of 1,000 adults who will be affected by cancer due to exposure to haze due to forest and land fires in in Sawahlunto City.

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