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Air Quality Evaluation: Assessment of Heavy Metals in Dust at the Indonesian National Nuclear Energy Agency

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Abstract Air quality is a critical aspect in ensuring a healthy and sustainable living environment. One aspect of major concern is air contamination by heavy metals, especially in the form of dust. Heavy metals are chemical compounds that can have negative impacts on human health and the ecosystem as a whole. This study aims to investigate the distribution of heavy metals in airborne dust and their impact on air quality. This study is categorized into a descriptive type that describes the concentration of heavy metals in dust. Cross-sectional is the study design used. Quantitative data includes the concentration of heavy metals present in filter paper dust. The research was conducted at BRIN (National Research and Innovation Agency). Concentrations of 12 elements: Fe, Au, Pd, Se, Mo, Cu, W, Ni, Sn, Zn, Ir, Sb in ambient airborne dust have been detected at six sampling locations, including the Environmental Safety Laboratory, Radioactive Laboratory, Basement, Saung, TENORM Testing Facility, and Parking Area. Metallic element contamination in airborne dust at the six sampling sites was mainly found in the Environmental Safety Laboratory room, consisting of Fe, Au, Pd, Se, Mo, Cu, W, Ni. Of all the known elements, only the presence of Pb is regulated in Government Regulation No. 41 of 1999 on air pollution control in Indonesia. The quality standard for Pb in Total Suspended Particulate (TSP) is 2 µg/Nm^3 or 2000 µg/Nm^3. Compared to the standards of developed countries such as USEPA, where the quality standard for Pb in ambient air has been set at 250 µg/Nm^3.

Keywords Air Quality, Air Pollution, Heavy Metal

1. Introduction

Air quality is a critical aspect of ensuring a healthy and sustainable living environment [1]–[3]. One aspect of major concern is air contamination by heavy metals, especially in the form of dust. Heavy metals are chemical compounds that can have negative impacts on human health and the ecosystem as a whole [4]–[6].

In recent decades, increased industrial, transportation, and mining activities have increased heavy metal emissions into the atmosphere [7], [8]. Dust containing heavy metals can be widespread, especially in urbanized and industrialized areas, creating significant potential risks to human health and ecosystems [9]–[11]. Some of the heavy metals commonly associated with air pollution include lead (Pb), mercury (Hg), cadmium (Cd), and nickel (Ni) [12], [13]. Heavy metals are one of the ambient air pollutants that are carried along with airborne particulates. The presence of heavy metals in ambient air can be caused by human activities or natural factors. Quality standards for heavy metals in ambient air are still not fully regulated in the Appendix of Indonesian Legislation P No. 41 of 1999 concerning Air Pollution Control, except for lead (Pb) which is measured by the gravity method of extraction analysis using the High Volume Air Sampler (HVAS) sampling tool and analyzed using Atomic Absorption Spectrophotometry (AAS), which is 2 $\mu g/Nm^3$ [14], [15].

The entry of particulates into the human respiration system is influenced by the size of the particulates. Particulates are categorized based on the size of their aerodynamic diameter. These divisions include PM_{10} (particulates with an aerodynamic diameter $\leq$ 10 μm) and $PM_{2.5}$ (particulates with an aerodynamic diameter $\leq$2.5 μm)[16]. Very fine particles can contain metals. Heavy metals in the form of particles can affect human health if they enter breathing and then penetrate into the human lungs, causing various diseases such as ARI, symptoms of anemia, obstacles in growth, a weak immune system, autistic symptoms, lung cancer, and even premature death. At the Center for Safety Technology and Radiation Metrology, BATAN, has national level environmental safety testing activities with activities using high chemicals that have a high risk to the health and safety of workers. Therefore, it is necessary to monitor the concentration of particulate dust contained in the air to improve the highest degree of health of workers at the Center for Safety Technology and Radiation Metrology, BATAN as a form of public health practice.

The importance of deeply understanding the impact of heavy metals on air quality is a key foundation for environmental mitigation and management efforts. Therefore, this study aims to investigate the distribution of heavy metals in airborne dust and their impact on air quality. Through a better understanding of air quality associated with heavy metals in dust, it is hoped that concrete measures can be taken to protect human health and maintain environmental sustainability. This research is expected to make a positive contribution to environmental policy planning, as well as provide a scientific basis for improving effective and sustainable clean air management efforts.

2. Materials and Methods

This study is categorized into a descriptive type that describes the concentration of heavy metals in dust. Cross-sectional is the study design used. Quantitative data includes the concentration of heavy metals present in filter paper dust.

The research was conducted at BRIN (National Research and Innovation Agency), an Indonesian government agency responsible for coordinating, developing, and advancing research and innovation in various sectors. The research was conducted indoors including the environmental health laboratory, radiochemical laboratory, and basement. The outdoor space includes a sauna, a Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) test facility, and a parking area.

Test sampling was conducted using the gravimetric method. The results are displayed in the form of units of particulate mass collected per unit volume. Test sampling was carried out at six location points. Heavy metal analysis using the XRF XMET- 5100 tool was carried out on particulate dust caught in the air sample filter. The elements analyzed were those in $PM_{2.5}$.

3. Result and Discussion

The range of analysis results of 12 elements: Fe, Au, Pd, Se, Mo, Cu, W, Ni, Sn, Zn, Ir, Sb contained in $PM_{2.5}$ in ambient air at 6 sample point locations of the Environmental Safety Lab, Radiochemical Lab, Basment, Saung, TENORM Test Facility, Parking Area, is presented in the table below.

Table 1. Measurement Results of Metal Element Contaminant Concentration

No.	Sample Name	Background Filter (%)		Measurement Results (%)		Contaminant Concentration (%)	
1	Safety Lab Environment 1	Fe	31,4	Fe	31,65	Fe	0,25
		Au	27,2	Au	27,3	Au	0,1
		Pd	16,7	Pd	20,667	Pd	3,9667
		Se	0,8	Se	0,8333	Se	0,0333
				Mo	2,8667	Mo	4,9
				Cu	2,2	Cu	4,9
				W	1,5	W	1,5
				Ni	1	Ni	1
2	Safety Lab Environment 2	Fe	31,4	Fe	41,567	Fe	10,167
		Au	27,2	Au	27,867	Au	0,6667
		Pd	16,7	Pd	22,8	Pd	6,1
				Mo	1,8333	Mo	1,8333
3	Safety Lab Environment 3	Fe	31,4	Fe	37,733	Fe	6,3333
		Pd	16,7	Pd	18,767	Pd	2,0667
				Mo	2,9333	Mo	2,9333
				Pb	1,9	Pb	1,9
4	Radiochemistry Lab 1	Fe	31,4	Fe	34,267	Fe	2,8667
		Sn	17,3	Sn	21,133	Sn	3,8333
				Mo	4,4333	Mo	4,4333
				Zn	1,8667	Zn	1,8667
5	Radiochemistry Lab 2	Fe	31,4	Fe	36,3	Fe	4,9
		Pd	16,7	Pd	14,833	Pd	1,8667
				Mo	1,3	Mo	1,3
				Ir	1,1667	Ir	1,1667
				Cu	2,0333	Cu	2,0333
				Zn	1,9667	Zn	1,9667
6	Radiochemistry Lab 3	Fe	31,4	Fe	38,2	Fe	6,8
		Au	27,2	Au	31,133	Au	3,9333
		Pd	16,7	Pd	21,167	Pd	4,4667
				Mo	2,7667	Mo	2,7667
7	Basement 1			Pb	2,2333	Pb	2,2333
				Zn	2,1667	Zn	2,1667
				W	2,9	W	2,9
				Cu	2,0667	Cu	2,0667
				Mo	1,1667	Mo	1,1667
				Sb	6,4667	Sb	6,4667
8	Basement 2	Fe	31,4	Fe	36,567	Fe	5,1667
		Sn	17,3	Sn	21,467	Sn	4,1667
				Mo	2,4	Mo	2,4

Table 1 continued

9	Basement 3	Fe	31,4	Fe	37,467	Fe	6,0667
		Pd	16,7	Pd	18,9	Pd	2,2
				Mo	2,6333	Mo	2,6333
				Zr	0,9	Zr	0,9
10	Saung 1	Fe	31,4	Fe	44,767	Fe	13,367
		Pd	16,7	Pd	17,733	Pd	1,0333
11	Saung 2	Fe	31,4	Fe	39,567	Fe	8,1667
				Zr	10,433	Zr	10,433
				Mo	1,1667	Mo	1,1667
12	Saung 3	Fe	31,4	Fe	34,167	Fe	2,7667
		Pd	16,7	Pd	20,167	Pd	3,4667
				Zr	20,367	Zr	20,367
				Pb	1	Pb	1
				Mo	1,5	Mo	1,5
				Ir	1,0667	Ir	1,0667
13	Test Facility TENORM 1	Pd	16,7	Pd	18,467	Pd	1,7667
				Zr	32,967	Zr	32,967
				Cu	1,4333	Cu	1,4333
14	Test Facility TENORM 2	Fe	31,4	Fe	39,933	Fe	8,5333
				Zr	19,733	Zr	19,733
				Cu	0,9333	Cu	0,9333
15	Test Facility TENORM 3	Fe	31,4	Fe	44,867	Fe	13,467
		Au	27,2	Au	29	Au	1,8
		Pd	16,7	Pd	19,2	Pd	2,5
16	Parking Area 1	Fe	31,4	Fe	42,3	Fe	10,9
		Pd	16,7	Pd	16,867	Pd	0,1667
				Zr	9,6667	Zr	9,6667
17	Parking Area 2	Fe	31,4	Fe	43,167	Fe	11,767
				Zr	22,833	Zr	22,833
				Cu	0,9333	Cu	0,9333
18	Parking Area 3	Fe	31,4	Fe	38,933	Fe	7,5333
		Pd	16,7	Pd	17,633	Pd	0,9333
				Zr	15,133	Zr	15,133

From the Table 1, it is known that at location point 1 of the Environmental Safety Lab there are heavy metals, namely Fe, Au, Pd, Se, Mo, Cu, W, Ni, Pb. Location 2 in the Radiochemistry Lab has heavy metals, namely: Fe, Sn, Mo, Zn, Pd, Cu, Ir. Location point 3 Basement there are heavy metals, namely: Pb, Zn, W, Cu, Mo, Sb, Sn, Zr, Location 4 Saung there are heavy metals, namely: Fe, Pd, Zr, Pb, Mo, Ir, Location 5 Ternorm Test Facility namely: Pd, Zr, Cu, Fe, Au, Location 6 has heavy metals, namely: Fe, Pd, Zr, Cu.

The concentrations of Fe, Au, Pd, and Cu metals in Safety Lab - Environment 1, although generally low, still require health risk evaluation. The significant concentration of Pd (3.9667) may pose potential health impacts. Palladium (Pd) is known to have allergenic and toxic properties especially on long-term exposure, with effects possibly involving the respiratory system, skin and internal organs. High concentrations of Fe metal in Safety

Lab - Environment 2, especially at the 10.167% level, may increase health risks for exposed individuals. The health impacts are Iron metal poisoning can cause conditions such as hemochromatosis [17], which can damage internal organs such as the liver, pancreas, lungs, and heart. According to research conducted by Teguh Prayudi in the metal casting industry located in Ceper District, Klaten Regency, Central Java Province, it is known that significantly high Fe values will cause pollution in the form of lung fibrosis, and can cause mucosal irritation [17]. The presence of toxic Pb metal in Safety Lab - Environment 3 needs to be a major concern. Fe and Pd metal concentrations are quite high. High exposure to lead (Pb) of 6.1 can cause lead poisoning with symptoms such as headaches, fatigue, allergic reactions and toxic effects, especially on the lungs and skin, and serious impacts on brain and nervous system development in children. Low levels of Pb cause irreversible brain damage that affects learning disorders/memory and decline. According to Yulia et al. [18], exposure to lead metal in the human body can disrupt the metabolic system, disrupt the formation of hemoglobin, cause neurological damage, and disrupt the reproductive system, heart, and kidneys. High concentrations of iron (Fe) at 6,333 can potentially trigger hemochromatosis, causing fatigue, joint pain, and liver disorders [19], [20]. In addition, the cumulative impact of simultaneous exposure to heavy metals can exacerbate symptoms and health risks, with interactions between metals in the body that can produce more complex and serious effects compared to single exposures [21], [22].

In Radiochemistry Lab 1, it was found that high concentrations of the metals Sn (3.8333) and Mo (4.4333) can increase the risk of exposure to potentially harmful toxins, especially in organs such as the respiratory system and circulatory system. Prolonged exposure can contribute to metal poisoning, causing impaired organ function and serious health problems. Fe metal concentration in Radiochemistry Lab 2 of 4.9 may increase health risks for exposed individuals. The health impacts are Iron metal poisoning that can lead to conditions such as hemochromatosis, which can damage internal organs such as the liver, pancreas, and heart. The presence of Au, Fe, and Pd at high levels in Radiochemistry Lab 3. The highest concentration of heavy metals is Fe (6.8). If metal concentrations exceed threshold values, human health impacts may include respiratory distress, skin irritation, and risk of chronic disease [23]–[25]. Meanwhile, environmental impacts may include soil and water contamination, potentially harming local ecosystems [26], [27].

The high Sb metal concentration of 6.4667 in Basement 1 may pose a significant health risk. Continued exposure to this metal can lead to antimony poisoning, which has serious health impacts [28], [29]. Antimony poisoning can cause symptoms such as nausea, vomiting, stomach disorders, and nervous system disorders [30]. High levels of exposure can also contribute to respiratory problems, skin irritation and impaired liver function. In Basement 2, Sn metal has a high concentration (21.467%) and needs to be evaluated for risk. Sustained exposure to high concentration levels of Lead metal can lead to lead poisoning or plumbism, which can affect the nervous system, cause anemia, and even damage vital organs such as the kidneys and liver [31]. Meanwhile, significant concentrations of Iron metal can increase the risk of developing the condition hemochromatosis, in which the body absorbs and stores excessive amounts of iron, damaging internal organs such as the liver, pancreas, and heart. Researchers Susilo and Tunjungsari [32] reported that welding workers exposed to iron-containing welding fumes cause asthma, pneumonia, pulmonary fibrosis, and lung cancer. Basement 3 showed high concentrations of Fe (6.0667%) and Pd (2.2%). Further evaluation is required to understand the source and potential impact of the contamination. The high Fe metal content may pose a health risk, especially in relation to conditions such as hemochromatosis, where excessive iron absorption and storage in the body can damage internal organs [33], [34]. Meanwhile, the presence of significant concentrations of Palladium (Pd) also requires further attention, as high exposure can cause allergic reactions and toxic effects on the lungs, skin and other organs [35], [36].

Saung 1 showed a high concentration of Fe metal (13.367%), and Pd with a concentration of 1.0333%. High Fe metal content can increase the risk of conditions such as hemochromatosis, where the body absorbs and stores excessive amounts of iron, which can be detrimental to internal organs such as the liver and pancreas. In addition, the presence of Palladium (Pd) in significant concentrations also requires attention, as high exposure can cause allergic reactions and toxic effects on the lungs, skin and other organs. Saung 2 showed the presence of high concentrations of Zr metal (10.433%). Zirconium can have toxic effects on humans, especially in the event of high amounts and prolonged exposure. Health impacts from Zr exposure can include irritation to the respiratory system, skin and other organs [37], [38]. In addition, the presence of noteworthy concentrations of Iron (Fe) metal can also increase the risk of developing conditions such as hemochromatosis, which can be detrimental to internal organs[39]–[41]. In Saung 3, Fe and Pd metals have high concentrations (2.7667% and 3.4667% respectively). Fe metal concentrations can increase the risk of hemochromatosis, which can cause damage to internal organs such as the liver and pancreas. Meanwhile, Pd can cause allergic reactions and toxic effects, especially on the respiratory system and skin [42], [43].

The TENORM 1 Test Facility showed high concentrations of the metals Zr (32.967%) and Pd (1.7667%). Zr can have toxic effects especially on organs such as the lungs and kidneys, while Pd can cause allergic reactions and negative impacts on the respiratory system. Long-term exposure to high concentrations of these two metals may contribute to an increased risk of diseases and health problems. TENORM Test Facility 2 showed high concentrations of Fe (8.5333%) and Zr (19.733%). Long-term exposure to these metal particles can pose a health risk to the population living or working around the area [44]. Metal dust such as Fe and Zr can enter the human respiratory tract and cause respiratory distress, and irritation to the eyes, nose and throat. Metal particles in the air can also settle to the ground or water table, potentially contaminating the environment. The TENORM 3 Test Facility showed high concentrations of Fe (13.467%) and Au (1.8%). Iron (Fe) metal in high concentrations can cause a variety of health problems, including disruption to the circulatory system, irritation to the respiratory tract, and the potential for conditions such as hemochromatosis [45]. Meanwhile, Gold (Au) metal has a more focused impact on the environment, where increased concentrations of gold can lead to water and soil pollution [46].

Parking Area 1 shows a high concentration of Fe metal (10.9%). High levels of Iron (Fe) metal can cause a poisoning known as hemochromatosis, in which the body absorbs and stores excessive amounts of iron [47], [48]. This can cause disruption to the circulatory system, irritation to the respiratory tract, and can be detrimental to internal organs such as the liver and heart. In addition, environmental impacts are also a concern, as excess metals in the soil can contaminate groundwater and affect local ecosystems [49]. Parking Area 2 shows high concentrations of Fe (11.767%) and Zr (22.833%) metals. Continued exposure to high concentrations of Fe metal can result in health risks, such as disruption to the circulatory system, irritation to the respiratory tract, and poisoning [50]. Meanwhile, high concentrations of Zr can have a toxic impact on organs and cause health problems [51]. Parking Area 3 shows high concentrations of Fe (7.5333%) and Pd (0.9333%). Long-term exposure to high concentrations of Fe metals can cause health risks, including disruption of the circulatory system, irritation of the respiratory tract, and potential damage to internal organs. Pd, although in lower concentrations, still requires attention as it can cause allergic reactions and toxic effects on the lungs, skin and other organs.

Dust heavy metals and the nuclear industry are related in the context of the release of radioactive substances that can generate dust particles containing heavy metals. The nuclear industry involves processes such as nuclear fuel processing, radioactive waste management, and other nuclear-related activities. Some heavy metals, such as lead (Pb), mercury (Hg), and cadmium (Cd), can be components of dust associated with these activities. In the nuclear fuel production phase, especially in nuclear processing facilities, there is the potential for the release of dust particles containing heavy metals [52]. Processes such as grinding, crushing, and isotope separation can generate dust containing these heavy metals. Radioisotope release in the event of an accident or incident at a nuclear facility, radioactive substances may be released into the environment. Heavy metal dust can be one of the media through which these radioactive substances are spread, especially in the event of a fire or explosion [53]. Radioactive waste, and radioactive waste management at nuclear facilities can involve the manipulation of materials that have the potential to generate dust containing heavy metals [54]. At this stage, it is important to implement effective dust control measures to prevent unwanted releases. Radiation and toxicology of heavy metals some heavy metals have radioactive and toxicological properties that need to be taken into account in the context of the nuclear industry. The presence of heavy metal radioactive contaminated dust can increase the risk of exposure to radiation and toxic substances for workers and the surrounding community. The link between air quality and the nuclear industry demands special attention to environmental protection and public health. Dust management, environmental monitoring, and compliance with nuclear safety standards are key in minimizing the negative impacts associated with heavy metal dust in the context of the nuclear industry [55].

4. Conclusions

The concentration of 12 elements: Fe, Au, Pd, Se, Mo, Cu, W, Ni, Sn, Zn, Ir, Sb contained in dust in ambient air has been detected at 6 sample point locations of Environmental Safety Lab, Radiochemical Lab, Basment, Saung, TENORM Test Facility, Parking Area. Contamination of metal elements contained in dust in the air to the six sampling point areas is mostly found in the environmental safety laboratory room, consisting of Fe, Au, Pd, Se, Mo, Cu, W, Ni. Of all the known elements, only the presence of Pb is regulated in Government Regulation No. 41 of 1999 concerning air pollution control in Indonesia. The quality standard for Pb in Total Suspended Particulate (TSP) is 2 $\mu g/Nm^3$ or 2000 $\mu g/Nm^3$. Compared to the standards of developed countries such as USEPA, where the quality standard for Pb in ambient air has been set at 250 $\mu g/Nm^3$. Data on the results of monitoring the monitored elements can serve as basic data and become the basis for making policies in an effort to restore environmental quality, especially ambient air.

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