Environmental health risk assessment of manganese and cadmium in the ground water around Cipayung Landfill in Depok, Indonesia

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Abstract. The existence of landfill is a risk to release various metals into the environment, such as Manganese (Mn) and Cadmium (Cd). Mn and Cd can cause serious and toxic effect for health if excessive intake. This study was conducted to identify the health risks of Cd and Mn intake in Cipayung Landfill Depok. The samples were 104 respondents and 66 ground water samples at a radius of 0-500 meters from the landfill. Cd and Mn Measurement in the ground water used atomic absorption spectrophotometry. Health risk analysis was determined based on hazard identification, dose-response assessment, exposure assessment and risk characterization. Mn and Cd concentration were 0.06-0.84 mg/L and <0.001 mg/L, respectively, while the average daily consumption of ground water was 2.18 L. Mn and Cd Chronic Daily Intake (CDI) were 0.008 mg/kg/day and 0.00005 mg/kg/day, respectively. Mn and Cd Hazard Quotient (HQ) were not more than 1 with maximum Mn and Cd HQ, 0.2 and 0.08, respectively. It can be concluded that the concentration of Mn and Cd in groundwater consumption in the community around the Cipayung landfill is categorized as not having risk to health, even though there are 9 ground water samples with Mn concentrations exceeding 0.4 mg/L.

Keywords: Manganese, Cadmium, Environmental Health Risk Assessment, Ground Water

1. Introduction

Manganese (Mn) is a normal element in air, soil, water and food. Mn can be found in air, soil and water after being released from the manufacturing: usage and waste processes that use Mn. Mn cannot be decomposed in the environment. Mn can only change shape to be bound or separated from particles. Most of the Mn in water tends to stick to other particles or settle into sediment. The presence of Mn is abundant on earth, which consists of about 0.1% of the earth's crust [1].

Whereas cadmium can be released into soil, water and air by non-ferrous metal mining and refining, manufacturing and application of phosphate fertilizer, fossil fuel burning, and combustion and waste disposal. Cadmium can accumulate in aquatic organisms and agricultural crops. Cadmium and its compounds can spread through the soil, but their mobility depends on several factors such as pH and the amount of organic matter [2].

Mn is an important element for living organisms, including humans. In contrast to Mn, Cd is a non-essential heavy metal for the body and is toxic [3,4]. In Indonesia, the permissible concentration of Mn in drinking water is <0.4 mg / L while Cd is 0.003 mg / L [5]. One of environments that is at risk of releasing Mn and Cd into the environment is landfill. Leachate is the main threat to groundwater quality. Leachate is the result of liquid waste dumped in landfill and decomposition of solid waste (assisted by...
rain and surface runoff). Therefore, improper disposal will increase the presence of toxic and dangerous chemicals in leachate [6].

One of landfills in Indonesia is the Cipayung Landfill. The landfill has been operating since 1984 with an area of \( \pm 10.8 \) hectares with a landfill area of \( 5.1 \) hectares consisting of pond A (2.1 hectares), pool B (2.4 hectares) and pond C (0.6 hectares off) in 2006. The Cipayung Depok TPA is a West Java Environmental Management Program (WJEMP) project and is a pilot TPA for the TPA in the Jabotabek area (Jakarta-Bogor-Tangerang-Bekasi). In 2011 pool C was completely closed because landfill conditions were too high and too close to residential areas, so that disposal was only in zones A and B. In 2015 Cipayung landfill Depok experienced a landslide to the middle area so that zones A and B became one with altitude reaches \( \pm 30 \) meters[7].

Most people who live around the Cipayung Landfill Depok still use ground water as raw material for drinking water. Based on the results of a preliminary study conducted at 2 Cipayung landfill points in Depok, namely at the coordinates S06°25.440'E106°47.390 'and S06°25.125'E106°47.263' the chemical measurement results got Mn concentration at one point exceeded the quality standard is 0.52 mg/L. The concentration has exceeded the concentration recommended by WHO, which is a maximum of 0.4 mg/L. So in this case, the study aims to identify the concentration of Mn and Cd around the Cipayung Landfill Depok using the environmental health risk assessment method. In order to get the value of RQ (Risk Quotient) which can interpret the level of safety of Mn intake in community drinking water. Previous studies have never analyzed the health risks from the concentration of Mn and Cd intake of drinking water in communities around Cipayung landfill. In this study, the measurement of Mn and Cd concentrations was not limited to administrative areas, but it used a buffer line up to 500m from the center of the landfill which had never been done before in previous studies.

2. Methods

2.1. Study Population and Sample

The administrative area of the Cipayung Landfill covers Cipayung and Pasir Putih districts. The total population of the study is 53,259 people and the number of research samples is 104 people. The research sample was obtained using the Probability Proportional to Size (PPS) method from the two Urban Villages. Research respondents only involved people who consumed ground water as raw material for drinking and cooking water. The number of groundwater samples taken is 66 samples taken from the nearest radius up to 500m from the center of the landfill. The method of taking ground water used the SNI 06-2412-1991 method. Measurement of Mn concentration in ground water used SNI 6989.5: 2009 spectrophotometry.

The research sampling area was divided into 4 main points (figure 1). This was intended to facilitate data collection. At a radius of 0-500m from the center of the Cipayung landfill, not all of the land area was used for settlements. As the consequence, there were several vacant land locations.

2.2. Environmental Health Risk Assessment

The study used the concept of Environmental Health Risk Analysis which consisted of four steps, namely hazard identification, dose-response assessment, exposure assessment and risk characterization [8]. RQ value calculation used the following formula.

\[
CDI = \frac{C_w \cdot DI \cdot EF \cdot EP}{BW \cdot AT}
\]

\[
HQ = \frac{CDI}{RfD}
\]

\( C_w \) (mg/L) is the concentration of Manganese and Cadmium, \( DI \) (L/day) is daily average intake of water, \( EF \) (days/year) is the annual exposure frequency using 365 days/year, \( EP \) (year) is exposure period using default residential 30 years, \( BW \) (kg) is body weight, \( AT \) is time average, for non carcinogen substance (Mn) \( EP \times 365 \) days and carcinogen substance (Cd) 70 year x 365 day, \( RfD \) is reference dose of each substance obtained from EPA (RfD of Mn is 0.14 mg/kg/day and RfD of Cd is 0.0005 mg/kg/day) [1,2].
This study used descriptive analysis for all variables with statistic software. Calculations using the formula above were used to measure the CDI and HQ values of each respondent. Meanwhile, health risk factors (age, gender, blood sugar, blood pressure, heart disease, body mass index, family history of illness, cigarette and alcohol consumption) were analyzed to see the frequency distribution. In this study, we did not correlate HQ values with disease.

![Figure 1. Research Sites [9].](image1)

![Figure 2. Ground Water Sampling Points According to Mn Concentration Around Cipayung Landfill.](image2)

### 3. Results

Mn concentrations in excess of 0.4 mg / L were unevenly distributed in the 4 sampling areas (Figure 2). Out of 66 sampling points, 9 points have levels of Mn > 0.4 mg/L (table 1). From the 4 sampling areas, the highest number of points that had ground water > 0.4 mg/L was sampling area 2, which was 6 points (28.6%) (table 1). The sampling area 2 is the basin area compared to the other 3 areas. Based on observations, if moving from sampling area 1 then sampling area 1 has high soil topography. The more it moves to the sampling area 2, the land tends to slope and from the sampling area 2 to 3 the topography of the land gets higher up to the sampling area 4. This is consistent with the profile of the City of Depok as stated in the Depok City Medium Term Investment Program Plan that the Cipayung District and Sawangan District are a weak undulating hilly area with elevation > 110 meters above sea level [10]. While the concentration of Cd from 66 points obtained results below the detection limit of the measuring instrument, which is <0.001 mg / L.
Table 1. Groundwater Sample Distribution According to Mn and Cd Concentration Per Sampling Area Around Cipayung Landfill.

| Sampling Area | Number of Sampling Points (n) | Number of Sampling Points Exceeding Manganese Quality Standard (n) | Number of Sampling Points Exceeding Cadmium Quality Standard (n) |
|---------------|-------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1             | 13 (19.70%)                   | 1 (11.11%)                                                    | 0 (0%)                                                        |
| 2             | 21 (31.82%)                   | 6 (66.67%)                                                    | 0 (0%)                                                        |
| 3             | 21 (31.82%)                   | 2 (22.22%)                                                    | 0 (0%)                                                        |
| 4             | 11 (16.66%)                   | 0 (0%)                                                        | 0 (0%)                                                        |
| **Total**     | **66 (100%)**                 | **9 (100%)**                                                  | **0 (100%)**                                                  |

Manganese quality standard > 0.4 mg/L [11]  
Cadmium quality standard > 0.005 mg/L [11]

Table 2. Community Health Risk Factors Around Depok Cipayung Landfill.

| Health Risk Factors               | Frequency (n) | Percentage (%) |
|-----------------------------------|---------------|----------------|
| Age                               |               |                |
| 18-50 years                       | 74            | 71.2           |
| 50-64 years                       | 30            | 28.8           |
| Gender                            |               |                |
| Male                              | 12            | 11.5           |
| Female                            | 92            | 88.5           |
| Blood sugar                       |               |                |
| Diabetes                          | 4             | 3.8            |
| Normal                            | 100           | 96.2           |
| Blood pressure                    |               |                |
| Hypertension                      | 16            | 15.4           |
| Normal                            | 88            | 84.6           |
| Heart disease                     |               |                |
| Have heart disease                | 5             | 4.8            |
| Have no heart disease             | 99            | 95.2           |
| BMI                               |               |                |
| Obesity                           | 54            | 51.9           |
| No obesity                        | 50            | 48.1           |
| Family history of illness         |               |                |
| Have family history of illness    | 62            | 59.6           |
| Have no family history of illness | 42            | 40.4           |
| Cigarette consumption             |               |                |
| Smoking                           | 7             | 6.7            |
| Non smoking                       | 97            | 93.3           |
| Alcohol consumption               |               |                |
| Consumption                       | 2             | 1.9            |
| No consumption                    | 102           | 98.1           |

From table 2, the majority of respondents aged 18-50 years as many as 74 people (71.2%). Of the 104 respondents, most were female, 92 people (88.5%). One of the target organs of Mn and Cd is the kidney. Other risk factors for kidney disease besides Mn and Cd are diabetes, blood pressure, heart disease, obesity, family history, cigarette and alcohol consumption. Based on table 2, most respondents did not have diabetes (3.8%), blood pressure (15.4%), heart disease (4.8%). While the majority of respondents were obese (51.9%) and had a family history of illness (59.6%) such as kidney disease,
heart disease, hypertension, diabetes and obesity. A small proportion of respondents consumed cigarettes (6.7%) and alcohol (1.9%).

**Table 3. Health Risk Analysis.**

| Variable                     | Min | Max | Mean  | SD  |
|------------------------------|-----|-----|-------|-----|
| Age (year)                   | 21  | 64  | 43.47 | 10.59 |
| Body weight (kg)             | 34  | 98.85 | 58.63 | 12.08 |
| Body mass index (kg/m²)      | 14.62 | 40.41 | 25.56 | 4.96 |
| Mn concentration (mg/L)      | 0.06 | 0.84 | 0.20  | 0.19  |
| Cd concentration (mg/L)      | <0.001 | <0.001 | - | - |
| Daily intake of water (L)    | 0.10 | 5.03 | 2.18  | 0.83  |
| CDI Mn (mg/kg/day)           | 9.10⁻³ | 3.10⁻² | 8.10⁻³ | 7.10⁻³ |
| CDI Cd (mg/kg/day)           | 6.10⁻⁵ | 4.10⁻⁵ | 2.10⁻⁵ | 6.10⁻⁶ |
| HQ Mn                        | 6.10⁻¹ | 2.10⁻¹ | 5.10⁻² | 5.10⁻² |
| HQ Cd                        | 1.10⁻³ | 8.10⁻² | 3.10⁻² | 1.10⁻² |

According to table 3, respondents aged 21-64 years are with an average body weight of 58.63 kg. The average BMI is 25.56 kg / m². The concentrations of Mn and Cd are 0.06-0.84 mg / L and <0.001 mg/L, respectively. While the average daily consumption of ground water is around 2.18 L. The minimum consumption of ground water is 0.10 L because the respondent uses a source of drinking water other than ground water, which is refill water. The average CDI Mn and Cd is 0.008 mg / kg / day and 0.00005 mg / kg / day. Whereas HQMn and Cd are not more than 1, i.e. maximum Mn and Cd HQ are obtained, 0.2 and 0.08, respectively.

Below is a calculation example of the maximum HQ value of Mn and Cd from this study.

\[
CDI (Mn) = \frac{Cw.DI.EF.EP}{BW.AT} \times \frac{0.52 \text{mg/L.324L.365 day/year.30 year}}{62.35 \text{Kg.(30 year.365 day)}}
\]

\[
CDI (Mn) = 0.027 \text{mg/kg/day}
\]

\[
HQ (Mn) = \frac{CDI}{RF_D} = \frac{0.027 \text{mg/kg/day}}{0.14 \text{mg/kg/day}} = 0.2
\]

\[
CDI (Cd) = \frac{Cw.DI.EF.EP}{BW.AT} \times \frac{0.001 \text{mg/L.44LB.365 day/year.30 year}}{44.65 \text{Kg.(70 year.365 day)}}
\]

\[
CDI (Cd) = 3.92 \times 10^{-5} \text{mg/kg/day}
\]

\[
HQ (Cd) = \frac{CDI}{RF_D} = \frac{0.000039 \text{mg/kg/day}}{0.0005 \text{mg/kg/day}} = 0.08
\]

4. Discussion

4.1. Hazard Identification

Mn is an essential nutrient for intracellular activity. Mn function is as a cofactor for various enzymes, including arginase, Glutamine Synthetase (GS), pyruvate carboxylase and Mn Superoxide Dismutase (Mn-SOD). Through metalloprotein, Mn plays a very important role in growth or development, digestion, reproduction, defense of antioxidants, energy production, immune response and regulation of neuron activity. Mn deficiency is rare because Mn is mostly contained in food in general. Conversely, Mn poisoning can occur in excessive metal exposure. Excessive Mn tends to accumulate in the liver, pancreas, bones, kidneys, and brain. Molecular mechanisms of Mn toxicity include oxidative stress,
mitochondrial dysfunction, misfolded protein, endoplasmic reticulum stress (RE), autophagy dysregulation, apoptosis, and other metal homeostasis disorders [12].

Mn can accumulate in the basal ganglia area of the brain and can cause a syndrome such as Parkinson's which is referred to as manganism [13-14]. Manganism caused by chronic overexposure of Mn can have a detrimental effect on the brain. Manganism is caused by nerve injuries in cortical and subcortical brain regions, specifically the basal ganglia [15].

Cd is a non essential element that is toxic to the body, targeting the kidney organs of the bones and lungs [2,4]. Cd found in food and water in low concentrations, (around 1–10%) will be introduced into the body through the digestive tract. After Cd is absorbed by the body, it is usually bound to proteins containing sulfhydryl groups such as metallothionein. Cd will then be deposited in the liver 30% and in the kidneys 30%, with the rest distributed throughout the body, with a half-life of twenty-five years. Cadmium can cause toxicity in several organs. The main target organs of Cd are the kidneys, bones and lungs [2]. Cadmium induces tissue injury by causing oxidative stress, epigenetic changes in DNA expression, inhibition or increased regulation of transport pathways especially in the proximal segment of the renal tubules, inhibition of heme synthesis and impaired mitochondrial function which potentially triggers apoptosis and glutathione depletion, such as having structural distortion due to renal protein binding of Cd to sulfhydryl groups [4].

Most of cadmium entering the body enters the kidneys and can remain for years. A small portion of cadmium that enters the body will exit slowly through urine and feces. The body can convert most of cadmium into harmless forms, but too much cadmium can overload the abilities of the liver and kidneys [2].

Based on Erlinna’s (2012) research on the quality of clean water around the Cipayung landfill in Depok, Mn concentrations decreased with increasing distance from the landfill. Decrease began at a distance of 150 meters by 0.1 mg/L and at a distance of > 150 meters-250 meters a constant result was obtained, which is 0.2 mg / L [16]. In the research of Handono (2010) the Mn concentration in the Cipayung landfill at 3 sampling points, namely monitoring wells was above the quality standard of 1.90 mg / L. The concentration of Mn in the location of wells of resident houses and houses across the river was still below the quality standard of 0.5 mg / L [17]. Based on the 2007 Depok City Environmental Status Report, there were 3 sampling areas on Jalan Kampung Bulak, Kapuran Village, Depok, including the landfill area, residents across the river and residents from where the gas were released. Out of these 3 sampling points, 1 of them exceeded the quality standard of around 3.0 mg/L in Bulak Village near the gas outlet [18].

The description of the average Mn concentration in drinking water in Depok City based on the study of Islamy, F (2020) in Bojong Sari, Cipayung and Sawangan Districts was 1.20 mg/L, 1.35 mg/L and 1.38 mg/L. The overall average Mn concentration of 75 sampling points from the 3 districts was 1.3 mg/L [19]. According to Anjani’s research (2019), that the average Mn concentration in the community in Depok City based on the results of the local water company Tirta Asista Depok 2018 was 0.22 mg/L with a range of 0.0015 mg/L-2, 82 mg/L [20]. Based on Hartono’s research (2010), the Mn concentration in the local water company Tirta Kahrupan raw water from the Ciliwung river was 0.209 mg / L [21].

Mn concentration in well water around landfill in Indonesia was between 0.01 mg/L-10.13 mg/L [21-30]. In this case, the average concentration of Mn around Cipayung landfill is in the range of Mn concentrations around other landfills in Indonesia. Variations in Mn concentrations also occur in research in other regions in Indonesia from groundwater and river. It was about 0.029 mg/L-2.6 mg/L [31-34]. Based on research results, the concentration of Mn in drinking water, tap water, wells and ground waters in various countries showed that the results were also varied (<0.1 mg/L-2.7 mg/L) [35-44].

Based on other studies around Cipayung landfill, concentration of Cd from 3 sampling points did not exceed 0.005 mg / L [17]. The concentration of Cd in groundwater, leachate and river water around other landfills in Indonesia was ranges from 0.0000455 mg / L - 0.25 mg / L [21-22, 45-47, 32] While the concentration of Cd was ranges from 0.002 mg / L - 0.062 mg / L in drinking water, well and river in non-landfill areas in Indonesia [48-50]. In other studies in several countries, the concentration of Cd in groundwater was 0.02 mg / L - 0.07 mg / L and 0 mg / L in tap water and bottled water [51-54].
4.2. Exposure Analysis

Mn and Cd can enter the body through inhalation, ingestion and skin. However, this study only calculates ingestion Mn exposure from ground water consumption. Based on the results of the study, the highest Mn concentration is 0.84 mg / L with an average concentration of 0.20 mg / L. While the concentration of Cd from all points <0.001 mg / L. Based on Erlinna's (2012) research on the quality of clean water around the Cipayung landfill in Depok, Mn concentrations decrease with increasing distance from the landfill. Decrease begins at a distance of 150 meters by 0.1 mg / L and at a distance of> 150 meters-250 meters a constant result is obtained, which is 0.2 mg / L [16]. In the research of Handono (2010) the Mn concentration in the Cipayung landfill at 3 sampling points, namely monitoring wells above the quality standard of 1.90 mg / L. The high Mn concentration in the monitoring well is probably due to the waters in anaerobic conditions due to the high decomposition of organic matter. Whereas the concentration of Mn in the well location of resident houses and houses across the river is still below the quality standard of 0.5 mg / L. Cd concentrations at three sample locations showed below the standard quality of 0.005 mg / L. The presence of cadmium (Cd) in water is very little (microorganic) and insoluble in water. Cadmium salts (chloride, nitrate, and sulfate) can be in the form of complex organic and inorganic compounds or absorbed into suspended materials and basic sediments [17].

4.3. Dose-response Analysis

Based on the estimated value of the daily Mn intake of the community around the Cipayung Depok landfill using ground water as raw material for drinking and cooking water, an average daily intake of 0.26 mg with a minimum daily intake of 0.01 mg and a maximum intake of 2.07 mg. Based on WHO (2011), with an average Mn concentration in drinking water of 10 μg / L, an Mn intake of 20 μg / L was assumed a water intake of 2 L / day [55]. In this case, the average and maximum daily Mn intake around the Cipayung landfill is higher than the estimated daily intake by WHO, while the minimum community Mn intake in drinking water is lower than WHO.

According to The Food and Nutrition Board of The Institute of Medicine, a adequate intake of Mn for adults is 1.8 mg / day for women and 2.3 mg / day for men. Based on adequate intake of Mn, the people who live around the Cipayung landfill have an intake value not exceeding the recommended intake. However, WHO states that the greatest intake of Mn is sourced from food, including nuts and products, grains and preparations, fruits, vegetables, meat, poultry meat, eggs, milk and tea [55]. Based on the results of interviews with respondents, the types of food intake of the most consumed Mn sources (more than 3 times a week) are cereals (100%), seasonings, fat, sweeteners (100%) and vegetables (87.5%). From these results, the possibility of accumulation of Mn intake in total ingestion exceeds the results of the study.

Although all sampling points obtained the same concentration of Cd, namely <0.001 mg / L, the intake of Cd for each respondent was different depending on the amount of water consumed. Based on the estimated CDI intake of groundwater, the average daily intake was 0.002 mg (0.0001 mg-0.005 mg). Based on the Agency Toxic for Substances and Disease Registry (2008), the minimum risk level of cadmium for chronic-duration oral exposure (≥ 1 year) is 0.001 mg / kg / day. Based on the CDI calculation of all respondents, the average CDI value is 0.00002 mg / kg / day (0.00004 mg / kg / day-0.0000006 mg / kg / day). Therefore, based on this calculation, the respondent's drinking water intake less than minimal risk level.

4.4. Risk Characterization

Based on the calculation results, the maximum value of CDI Mn does not exceed RfD which is 0.14 mg / kg / day, as well as CDI Cd does not exceed the RfD value of 0.0005 mg / kg / day. Whereas based on the calculation of the maximum HQ for each Mn and Cd values obtained <1, namely 0.2 and 0.08, respectively. Thus in this case, the intake of Mn and Cd in drinking water does not pose a risk to public health around the Cipayung Landfill Depok. Although, there are 10 points that have Mn concentrations > 0.4 mg / L.

There are different results in several studies related to HQ Mn and Cd. In Agustina's research (2019), the results of HQ Mn of drinking water in Pasuruan was <1 [56]. However, based on research in Rawakucing Landfill, it was found that 16.3% of people who consumed groundwater had HQ> 1 [30].
Based on the research of Ghosh et al (2020), the HQ value of manganese for adults from groundwater intake as drinking water was ranges from 0.019 to 2.459, while children had a maximum HQ value of 1.004 with an average manganese concentration of 0.298 mg/L (0.016 mg/L-2.108 mg/L) [57]. Other studies around the Pangkajene river obtained HQ of Cd values in almost all respondents > 1 with a concentration of Cd in water 0.005 mg/L - 0.015 mg/L and white shellfish 0.206 mg/L - 0.333 mg/L [58]. Based on a case study of the south of setif area, East Algeria, the average HQ Cd value from consuming groundwater was 4.17 with Cd concentrations ranging from 0.009 mg/L - 0.165 mg/L [59].

5. Conclusion
Mn concentration of 66 ground water points is obtained between 0.06 mg/L-0.84 mg/L (0.2 mg/L ± 0.19 mg/L) and all Cd concentrations from ground water points is <0.001 mg/L. The highest number of ground water points that has Mn concentration > 0.4 mg/L is sampling area 2, which is 6 points (28.6%). Sampling area 2 is a basin that is in the direction of the river, so it is possible that leachate tends to move to the sampling area 2. However, we did not examine the movement factor of Mn in the soil around the Cipayung landfill. HQ Mn and Cd was <1, so in this case the intake of Mn and Cd in the community around the Cipayung landfill did not indicate health risks, although 9 ground water points have Mn> 0.4 mg/L. The overall health risks of exposure to Mn and Cd are likely to be greater if they are accumulated from total exposures (ingestion, inhalation and skin) because we only assess this through intake of groundwater. Future studies are suggested to assess health risks based on the total concentrations of Mn and Cd by ingestion, inhalation and skin. In addition, the concentration of Mn in food must be measured because food is the largest source of Mn intake.

Ethical Considerations
This study was approved by The Research and Community Engagement Ethical Committee Faculty of Public Health Universitas Indonesia (Ket-698/UN2.F10/PPM.00.02/2019).

Competing Interests
The authors declared that no competing interests exist.

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