Soil and banana crops (Musa paradisiaca L.) risk by chromium (Cr) accumulation through leachate and its health risk assessment

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Abstract. The leachate efluen of Semarang landfill is directly flew to the upper course of Kreo river is a fact that make Kreo river is possibly contaminated by heavy metal. Many banana trees are planted around the contaminated soil. This study was conducted to determine Cr toxicity on banana trees that grow on contaminated soil and to determine public health risks that is caused by leachate of Semarang landfill. The measurement of bioaccumulation factor as the basic data for environmental safety and as the evaluation of wastewater processing is conducted through Cr level measurement. The research shows 1) Cr concentration on WWTP Jatibarang Semarang landfill’s efluen leachate in the rainy season exceeds the environmental safety limit. 2) Cr concentration in the water before and the after of efluen leachate contamination is under the standard. 3) Cr contamination in the soil around Jatibarang landfill’s efluen leachate contamination area exceeds its limit. 4) The bioconcentration factor shows the banana trees can accumulate Cr from soil to the tree. 5) Most of Cr accumulation in the banana trees is translocated to the air and to the root of the tree. 6) The banana plants such as root, stem and pseudostem from the Cr contaminated soil is safe for consumption.

1. Introduction
Heavy metal pollution is one of the world’s environmental problem since its distribution and toxic are dangerous for human health. Miss management of landfill as the waste recycling and processing area possibly contaminates the ecosystem through obstruction vegetation and environment. Heavy metal accumulation on the ground will lead the reduction of crops productivity and safety. Chromium is needed for the metabolism of proteins, fats and carbohydrates. Lack of Cr (III) causes some dysfunctional diseases of metabolism such as prolonged stress during pregnancy, physical trauma, and infection [1]. The excess Cr may cause nephrotoxicity. The chromium exposure causes inflammation of the skin, respiratory system, liver damage and ulcer formation [2]. The limitation of heavy metal intake in humans is needed. It is around 0.05–0.2 mg / day−1 [3].

Parts of banana tree such as roots, stems and pseudostems are often made as traditional medicine and traditional culinary. The application of banana tree’s parts as traditional medicine includes: root of banana tree that are used as blood medicines, gender and anthelmintic diseases; banana stem has antilithiatic activity which helps to reduce and breakdown the the formation of magnesium ammonium
phosphate stones with traces of potassium oxalate [4]; Pseudostem juice is used for the treatment of diarrhea, hemoptysis, cholera and dysentery [4, 5]. Part of the banana tree is also used as traditional culinary, among others: Banana stems are used as delicious food such as Sayur Ares (Lombok-NTB), Bura Piong Pa or banana stem chicken (Toraja-South Sulawesi), Sayur Bonggol Pisang (Yogyakarta); Pseudostem banana is used as a typical and delicious food by the Dayak Tribe - Kalimantan.

Further discussion about the metal absorption by crops and its health risk for human consumption, especially banana, is necessary. In Indonesia, investigation about heavy metal contamination on crops, which is connected on human health, is not popular, though there are certain references from foreigners’ researchers like [6, 7, 8]. The research’s purpose is to determine Cr toxicity on banana trees that grow on contaminated soil and to determine public health risks that is caused by leachate of Semarang landfill. The measurement of bioaccumulation factor as the basic data for environmental security and waste processing evaluation is conducted by measuring Cr.

2. Methods

2.1. Experimental Design Research Study

Samples is divided into 6 research stations: 1st station, effluence leachate; 2nd station, water condition before effluence leachate; 3rd station, water condition after effluence leachate; 4th station, the soil that is planted with banana in Jatibarang landfill area; 5th station, the soil that is planted with banana in Jatibarang landfill area; 6th station, the soil that is planted with banana in Jatibarang landfill area. Soil sampling is conducted by dredging down the soil around 30 cm deep. 200-gram extract sample is packaged in the labeled polyethylene plastic. Sampling is also conducted on banana tree. The root, stem, and pseudostem are taken than packaged in the labeled polyethylene plastic. All of samples are packaged correctly in the labeled polyethylene plastic then saved in the 4°C airtight sterile icebox. The samples are analyzed in research development: and Disease Control Center (BBTKLPP Yogyakarta). 

Cr concentration analysis uses an atomic absorption spectrophotometer.

2.2. Banana Contamination Estimation Risk

2.2.1. Bioconcentration Factor (BCF). Bioconcentration factor is a capability index of certain vegetation to accumulate certain metal which correlating with metal concentration on soil. Bioconcentration factor is calculated with this formula:

\[ BCF = \frac{C_{\text{plant}}}{C_{\text{soil}}} \]

Figure 1. Map showing the locations of sampling sites and the study area in Indonesia
C_plant is the concentration of heavy metals in plants. Meanwhile, C_soil is soil concentration. Higher BCF is compatible for phytoremediation vegetation and BCF > 2 is measured as higher score.

2.2.2. Translocation Factor (TF). Translocation factor is calculated to evaluate banana which potentially indicated as phytoremediation. This ratio is to indicate the translocation of metal from root to air parts by sample. Translocation factor is calculated with this formula:

$$TF = \frac{MC_{\text{stem}} + MC_{\text{pseudostem}}}{MC_{\text{root}}}$$

Where Metal Concentration trunk (MC_{\text{stem}}), Metal Concentration pseudostem (MC_{\text{pseudostem}}) and Metal Concentration root (MC_{\text{root}}).

2.2.3. Health Risk Index (HRI) Ratio Estimation ratio of vegetation sample contamination with oral doses reference is determined through Health Risk Index (HRI). Estimation of contamination is calculated by dividing the daily intake of metal (DIM) with its safe point. Index point that higher than 1 is not considered safe for human health [9].

Health risk assessment for human conducts Health Risk Index (HRI) is calculated with this formula:

$$HRI = \frac{DIM}{Rfd}$$

The daily intake of metal is written as DIM and oral doses reference is written as Rfd. Rfd point for Cr is 0.300 (mg kg\(^{-1}\) body weight d\(^{-1}\)) [10, 11]. Meanwhile, the daily intake of metal (DIM) is calculated with this formula [20]:

$$DIM = \frac{C_{\text{metal}}xC_{\text{factor}}xD_{\text{food intake}}/\text{body weight}}{\text{body weight}}$$

Metal concentration on banana tree is shown as C_{metal} (mg kg\(^{-1}\)). C_{factor} as the conversion factor, D_{food} as daily intake of banana and the body weight mean (BW) is written as body weight. Conversion factor of green banana into its dry weight is 0.085. Body weight estimation for adult people is 55.9 Kg and daily intake of vegetable for each person is considered on 0.345 kg\(^{-1}\) d\(^{-1}\) [12, 13]. In this research, adult’s body weight, for each, is arranged into 60 Kg [14]. The fruit and vegetable intake which is suggested by expert is less than 400 g/day [15].

2.2.4. Data Analysis The laboratory result is well-defined with descriptive quantitative research analysis through literature study.

3. Results and Discussion

3.1. Cr Concentration in Water Sample

| Table 1. Cr concentration in effluent leachate sample and river’s water sample before and after Kreo river. |
|-------------------------------------------------|-----------------|-------|
| Test Result (mg/L) | Max. Level | pH |  |
| **Efluen leachate** | 0.0840 | 0.05 | 8.3 |
| **Water sample- before effluent leachate** | < 0.0213 | 0.05 | 8.1 |
| **Water sample-after Efluen leachate** | < 0.0213 | 0.05 | 8.0 |

Max. Level’s reference is PP No.82 – 2001
The calculation of heavy metal concentration in the water sample can be seen in Table 1. Cr concentration in WWTP Semarang landfill’s efluen leachate exceeded its environmental safe limit, which around 0.0840 (mg/L). Meanwhile, Cr concentration in the water before and after the contamination of efluen leachate is below its standard. The result of laboratory examination shows that pH of efluen leachate and Kreo water sample have alkali on 8.0-8.3 point. Based on FAO [16], pH sample limit tolerance for irrigation water is 6.50-8.40. The water sample’s pH alkali characteristic cannot be accepted since it tends to be protected by the soil [17].

3.2. Cr Concentration in Soil Sample

The calculation of Cr concentration and pH in the soil can be seen in Figure 2 and Table 2. The heavy metal content in the soil which is taken from the efluen leachate area contains Cr < 4.569 until 19.899 mg/kg heavy metal concentration. Based on this data we can conclude that based on PP (Government Regulation) No 101 - 2014 about dangerous, poisonous waste material management (Bahan Berbahaya dan Beracun (B3)) Cr contamination in the soil surface of Jatibarang landfill’s efluen leachate contamination area exceeds its standard [18]. The Cr exceeding is caused by the Cr input in the soil which is affected by natural factors that are dominated by human activities.

3.3. Cr Concentration in the Sample of Banana (Musa Paradisiaca. L) on the Efluen leachate Contamination Area.

Banana tree needs a soil with wealthy nutrients and water. Its root is responsible for nutrients and water supply to grow. Heavy metal concentration on Banana Kepok (Musa Paradisiaca. L) is shown by Table 2.

3.3.1. Translocation of metal (TF values). Banana (Musa Paradisiaca. L) potential to translocate Cr from its root to the aerial parts (stem and pseudostem) can be seen in Table 2. TF point > 1 is detected in banana tree L1, banana tree L2, banana tree L3, banana tree L4, banana tree L5, banana tree L7 and banana tree L9. TF point < 1 is detected in banana tree L6 and banana tree L8.

| Land Sample | pH which is measured in soil sample |
|-------------|-------------------------------------|
| Land (L1)   | 8.2                                 |
| Land (L2)   | 7.54                                |
| Land (L3)   | 7.94                                |
| Land (L4)   | 7.29                                |
| Land (L5)   | 7.27                                |
| Land (L6)   | 7.27                                |
| Land (L7)   | 7.27                                |
| Land (L8)   | 6.89                                |
| Land (L9)   | 7.05                                |

**Figure 2.** pH in soil sample

| Land (L1) | Land (L2) | Land (L3) | Land (L4) | Land (L5) | Land (L6) | Land (L7) | Land (L8) | Land (L9) |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| pH        | 8.2       | 7.54      | 7.94      | 7.29      | 7.27      | 7.27      | 6.89      | 7.05      |

**Table 2.** Cr Accumulation Characteristic in Banana (Musa Paradisiaca. L) Measurement in Efluen leachate Contamination Area to Determine Indirect Movement from Root to Its Aerial parts and Cr Translocation from Soil to Banana

|          | C_plant (mg/kg) | C_soil (mg/kg) | BCF | TF  | DIM | HRI  |
|----------|-----------------|----------------|-----|-----|-----|------|
| Banana tree L1 | < 13.707       | 19.899         | < 0.69 | < 2 | < 0.004 | < 0.013 |
| Banana tree L2 | < 13.707       | 12.931         | < 1.06 | < 2 | < 0.004 | < 0.013 |
| Banana tree L3 | < 13.707       | 10.180         | < 1.34 | < 2 | < 0.004 | < 0.013 |
| Banana tree L4 | < 13.707       | 4.702          | < 2.91 | < 2 | < 0.004 | < 0.013 |
| Banana tree L5 | < 23.681       | < 4.569        | < 5.19 | < 3.82 | < 0.0084 | < 0.028 |
| Banana tree L6 | < 22.850       | < 4.569        | < 5.00 | < 0.73 | < 0.0081 | < 0.300 |
| Banana tree L7 | < 20.002       | 10.180         | < 1.96 | < 3.37 | < 0.0071 | < 0.023 |
| Banana tree L8 | < 31.634       | 10.146         | < 3.11 | < 0.41 | < 0.011 | < 0.036 |
Chromium (Cr) in the solid phase, Cr tends to be immobile, idle, and not dangerous. But it will change drastically when they in liquid phase. Chromium mobilization happens when Cr is mixed in the ground water, flowed to the lower place, then potentially enrich Cr concentration in the soil. Cr mobilization through the absorption process on organic and inorganic soil components or be precipitated as pure density. Cr leads an effect when it reacts with different soil components which then affecting its availability, mobility and solubility. Cr exists in the environment in the solid and liquid phases [19].

3.5. Cr in The Water Sampling

The existence of Cr in effluent leachate is connected with the contamination of hazardous and toxic waste materials (used batteries, woven fabrics, used packaging, iron, and steel) in landfill which releases Cr and another heavy metal in Kreo river. Lower Cr concentration in the water is caused by: 1) Waste technology management is not optimal. 2) Fitoremediation technology application to ensure water ecosystem which can be seen effluent leachate’s Cr that can be controlled through bioaccumulator plants in the lower course of Kreo river. The bioaccumulator plants is Typha latifolia and Eichhornia crasipes. 3) Heavy metal dilution in the water. This continuous wastewater processing which enters Kreo river creates Cr accumulation in the soil [4]. The pH level escalation can be caused by methane in leachate composition. The existence of methane is caused by a fact that the wastewater processing before the water is allowed to enter Kreo river, not degradates it perfectly. It affects the effluent leachate in the Kreo river. Besides that, it can be lead by the waste water management installation that conducts aeration system which produces over populated methane bacteria that is caused from the transformation of organic and acetate acids into metana [19].

3.6. Cr Heavy Metal in The Soil

Cr enters the soil caused by the washing of particles that are contained Cr through geochemical processes such as weathering or diagenetic reactions. The existence of Cr in here is as a cationic species [20]. Cr (III) tends to tie down its mobility and bioavailability since it forms a strong bonds with alumino-silicate clay, Fe / Al hydro oxide in soil and another soil organic matter. Soil in the effluent leachate area contamination of Semarang TPA has pH around 7.05-8.20 point. Alkaline characteristic of pH in here is caused by the raising of affinity in the soil through the increasing of the negative charge in the soil. The negative charge of Cr (VI) is responsible for the increasing of Cr (VI) mobility and bioavailability by expelling minerals, humus, and negatively charged clay in the soil. This process makes the increasing of pH. The increasing of pH tend to push. The metal precipitation [21]. The high number of soil metal concentration is caused by the WWTP Semarang landfill contamination. In this research, Cr has capability to accumulate heavy metal from soil to plants. The

### Table 2

| Banana tree | Cr Concentration (mg/kg) |
|-------------|--------------------------|
| L9          | 22.913                   |
| L5          | 4.569                    |
| L6          | 5.01                     |
| L8          | 4.01                     |
| L9          | 0.008                    |
| L5          | 0.026                    |

3.3.2. Plant Index to Accumulate Cr (Bioconcentration Factor (BCF)). Represents Banana (Musa Paradisiaca L.) to extract heavy metal from soil. Banana tree has strong capability to accumulate metal in its tissue. This fact can be seen in banana tree L4, banana tree L5, banana tree L6, banana tree L8 and banana tree L9, which has BCF Index > 2. The result shows that the concentration point of bananas which are planted in effluent leachate contamination area exceeds its limit. In this research, banana tree L5 (5.19) > banana tree L9 (5.01) > banana tree L6 (5.0) > banana tree L8 (3.11) > banana tree L4 (2.91) have capability to extract Cr. And the strongest capability to extract Cr is shown by banana tree L5 which has BCF Index 5.19.

3.3.3. Dietary Intake and Its Human Health Risk Assessment. DIM and HRI points on banana tree have been calculated. It can be seen on Table 2. The measurement shows that HRI point < 1. Contamination estimation risk which is got through divide daily intake of metal (DIM) with its safe limit minus one explains that banana plants such as root, stem and pseudostem which is planted in the contaminated soil is safe to be consumed by human.

3.4. Chromium (Cr)
soil sample that has high concentration point often has very high accumulation level [22]. Cr accumulation to the soil possibly happens since there is a contamination of hazardous and toxic waste materials in Jatibarang landfill. Bad waste water processing leads the waste interacts with its environment. This contact leads chemical transformation in the environmental system, and the metal can not degraded [22]. The heavy metal transformation from solid phase to liquid happens if there is a soil kasion changing, ph, or oxidation-reduction potential [19].

3.7. Cr Heavy Metal in Plants.
The increasing of Cr concentration in the roots is caused by the binding of Cr (III) and Cr (IV) to the cell’s wall, then the root of the reductase enzyme reduces Cr (VI) to Cr (III). The increasing of Cr concentration causes many damages to plants including limited root growth, leaf damage, and the reduction of biomass [22, 23].

3.8. Health Risk
Health risk measurement for banana trees that is planted in the efluen leachate contamination area in Jatibarang landfill is needed since it is often consumed by locals. DIM and HRI point is calculated is shown in Table 2. The result shows that the banana which is planted in the efluen leachate contamination area in Jatibarang landfill is safe for consumption. Nonetheless, WWTP Semarang landfill monitoring has to be conducted, since the safe point of banana plants such as root, stem and pseudostem consumption which is planted in the efluen leachate contamination area in Jatibarang landfill is caused by the capability of banana tree to filter the toxic. Another crops plantation in this contamination area has to be monitored since each plant has different capability to filter toxic, especially Cr contamination. This hypothesis is proven through HRI < 1 point, since the capacity heavy metal absorbment depends on the variety of the plants that can be changed by human and environmental factors [19].

4. Conclusion
The existence of Cr heavy metal in efluen leachate is connected with the contamination of hazardous and toxic waste materials (used batteries, woven fabrics, used packaging, iron, and steel) in landfill which releases Cr and another heavy metal in Kreo river. This study shows that leachate and soil in the efluen leachate contamination area of Semarang landfill exceeds environmental safety quality standards. The entry of leachate into the environmental system causes the accumulation of metals in the soil then becomes a potential problem when it enters the human body through the food chain. Leachate which is thrown into the Kreo river must be monitored continuously to prevent it polluting the environment. Bananas have the ability to attract Cr (phytoextraction) from the contaminated land. Bananas have the ability to do contaminant transpiration (Cr metal) by vaporizing the Cr into the atmosphere as a harmless material (fitovolatisation). This study confirms that parts of banana plants such as root, stem and pseudo stem are safe for human consumption. Plants that grow on contaminated land need to be assessed for its safety if they are to be used by humans. Risk management based monitoring is needed so that the ecosystem balance is maintained [24].

Acknowledgments
I would to say thank you to Allah SWT; DLH kota Semarang that have given their support and BBTKLPP Yogyakarta for its for their laboratory analysis. Especially, I present this research for my beloved husband “Achsar I. Archiyanto”, my little teacher “Alfarezel Enzo Elhasiq”, and my family.
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