Analysis of heavy metal pollution of chromium (Cr) and nickel (Ni) in soil at Putri Cempo Landfill, Indonesia

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Abstract. Putri Cempo Landfill uses open dumping which can increase the risk of soil pollution due to heavy metals. Heavy metal contamination is a critical issue because it negatively impacts human health and causes environmental damage that can threaten the sustainability of the economy and ecosystems at a global level. This study aims to analyse the current conditions regarding the concentration of heavy metals in the soil at Putri Cempo Landfill with the parameters of heavy metals Cr and Ni and to determine the impact of these heavy metals on human health. Analysis of Cr and Ni content was carried out using Atomic Absorption Spectrophotometry (AAS). Data analysis was carried out by comparing the content of heavy metals in the soil at Putri Cempo Landfill with the SNI on the Threshold Limit Value (NAB) of Heavy Metals in Sediment/Soil. The results of laboratory tests showed that there was a content of heavy metals Cr of 1.2279 mg/L and Ni of 0.94842 mg/L. It can be concluded that with the Cr and Ni content, the soil at Putri Cempo Landfill has exceeded the limits set by SNI so that it can be considered contaminated by heavy metals Cr and Ni. This finding points to the need for mitigation to reduce health and environmental risks. It is recommended to enhance public education, improve waste management, implement remediation techniques, and regularly monitor air and soil quality. These steps can protect health and reduce the long-term impact of pollution if carried out sustainably.

1 Introduction

Population growth and economic development have led to changes in the behavior, lifestyle, and consumption patterns of people around the world. These behavioral changes have also resulted in more waste being produced and increased demand for waste management infrastructure [1]. Various types of waste produced by the community such as organic waste, plastic, glass, stone, and scrap metal from construction are disposed of and piled up in one location, namely the final waste disposal site [2]. Ministry of Environment and Forestry [3]

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reported that 66.82% of waste has been managed by reducing and handling waste, while the remaining 33.18% of waste is unmanaged.

Landfilling or stockpiling is a very popular technique in various countries to manage municipal solid waste. However, the application of the landfill method as a Final Disposal Site (TPA) for waste also hurts the environment because the waste will undergo rotting, oxidation, decomposition, and eventually produce leachate [4]. Leachate can seep into the ground, and mix with groundwater up to 200 meters, following the direction of groundwater flow. Leachate contains many chemical and inorganic compounds, as well as heavy metals that are harmful to living things. This is caused by mixed waste that is dumped into the landfill, including paint containers, electronic devices, and used batteries. The composition of the compounds in leachate is influenced by this condition [5]. The environment affected by heavy metal contamination has become a major global issue, which directly impacts the health and sustainability of a country's economic development [6]. It is estimated that heavy metals can cause a number of problems in humans, such as cancer, heart disease, mental disorders, chronic fatigue, damage to the kidneys, brain, and sensory systems, and skin and bone problems [7].

Most landfills in Indonesia still use the open dumping method for waste management. This method causes many environmental problems, especially in the air, water, and soil components as well as public health around the landfill [8]. One of the landfills that still uses this method is the Putri Cempo Landfill located in Surakarta City, Central Java. The Putri Cempo Landfill is one of the main waste management facilities that serves the waste disposal needs of various areas around Surakarta. The waste management process at the Putri Cempo Landfill has various facilities such as collection and recycling areas, transportation, sorting, processing, and waste disposal [9]. The increasing population in Surakarta has resulted in the volume of waste entering the Putri Cempo Landfill continuing to increase. The increasing volume of waste at the Putri Cempo Landfill will further pollute the soil through leachate so the potential for soil contamination in the area around the Putri Cempo Landfill is greater. However, the presence of Putri Cempo Landfill is indicated to have an impact on the surrounding environment including soil pollution due to the concentration of hazardous metals in waste such as Cr and Ni. Cr particularly in its Cr^{6+} form, can trigger lung cancer, nasal ulcers, bronchial asthma, skin allergies, and genotoxicity [25]. Ni can cause nasal and lung cancer as well as skin allergies [27]. Both metals have the potential to damage DNA, cause chromosomal abnormalities [27], and affect the central nervous system, posing the greatest risk to children and the elderly with weakened immune systems. Soil that has been contaminated with these heavy metals can cause various health and environmental problems [10]. Research conducted by [11], showed that the concentration of Pb and Cd pollutants in the majority of soil samples exceeded the threshold values set for each heavy metal. This study aims to analyze the current conditions regarding heavy metal concentrations in the soil of Putri Cempo Landfill, Surakarta with different heavy metal parameters, namely Cr and Ni, and to determine the impact of heavy metals on human health.

2 Research Methodology

2.1 Time and Location

The study was conducted from April to May 2024. The research samples were obtained through direct observation at the Putri Cempo Surakarta Final Disposal Site (TPA) (Figure1). Sample preparation was carried out at the Soil Chemistry Laboratory, Faculty of Agriculture, Sebelas Maret University. Analysis of Heavy Metals Chromium (Cr) and Nickel (Ni) in the samples was carried out at the UPT Laboratory, Sebelas Maret University, Integrated

Chemistry Sub-Laboratory, with the implementation of health protocols and laboratory SOPs.

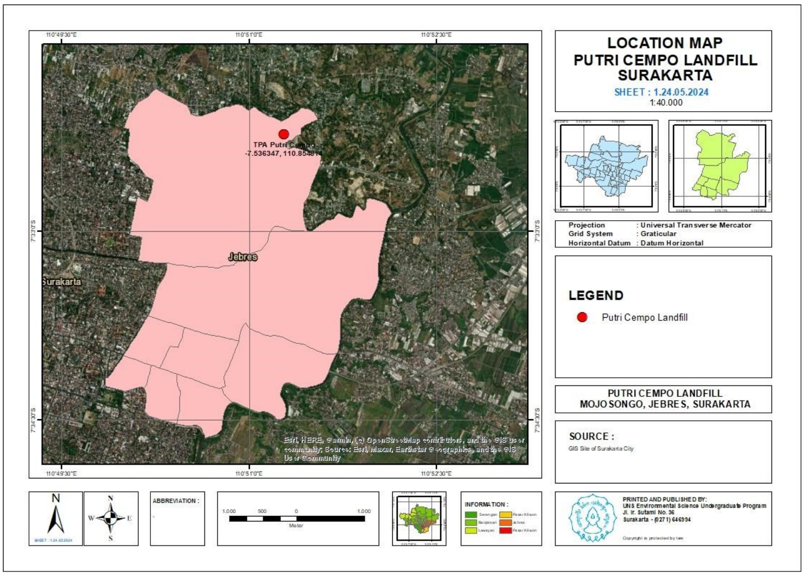

Figure 1. Map of the location of the Putri Cempo Surakarta Final Disposal Site (TPA).

2.2 Tools and Materials

The tools used in this study were dropper pipettes, 1 mL measuring pipettes, 500 mL beakers, 1000 mL and 100 mL measuring flasks, pumps, 50 mL and 500 mL Erlenmeyers, 25 mL measuring cylinders, funnels, Duran bottles, label paper, filter paper, and Atomic Absorption Spectrophotometry (AAS). The materials used in this study were soil samples from Putri Cempo Surakarta Landfill, distilled water, concentrated nitric acid (HNO_3), 1000 ppm Cr stock solution, Cr standard solution (0; 0.2; 0.5; 2.5; and 3 ppm), 1000 ppm Ni stock solution, Ni standard solution (0; 0.3; 2.5; 3.5; and 5 ppm).

2.3 Determining Sampling Points

Determination of sampling points for soil samples to be tested is carried out using a composite soil sampling method. The tools used to take composite soil samples are a small shovel, plastic container, pipe, and gloves. The SNI used for composite soil sampling is SNI ISO/EIC 17025: 2017 LP-814-IDN. The way this sampling works is by determining the sampling point in one of four ways (diagonal, zig-zag, systematic, and random). In taking soil samples at the Putri Cempo TPA, a random method was used. This composite soil sampling method is used because the samples taken at a certain point can represent the entire land or plot [12]. Soil samples are taken by inserting a pipe approximately 5-10 cm from the ground surface, then lifting the pipe slowly so that the soil does not come loose. Level the top and bottom surfaces of the pipe filled with soil so that no excess is included, then store the soil sample in the prepared container.

2.4 Heavy Metal Content Testing

Before testing the heavy metal content of the sample, the Putri Cempo TPA soil sample and standard solution were prepared first. The Putri Cempo TPA soil sample needs to be dried first, then ground and filtered to obtain fine grains. Furthermore, the soil sample will go through a destruction process to take the liquid sample. The standard solution was made using the stock solution for Cr and Ni metals as much as 10 ml, then mixed with 1000 ml of aquabidest, and 3.5 ml of concentrated nitric acid (HNO_3). Furthermore, the standard solution was made based on the standard series of each heavy metal parameter. will be tested. Then the sample and standard solution will be tested using the AAS (Atomic Absorption Spectrophotometry) tool. This Atomic Absorption Spectrophotometry can also be used to analyze the chemical elements in steel or iron [13].

2.5 Data Analysis

The data used for the calculation of the heavy metal content of Cr and Ni uses primary data and secondary data. Primary data is data obtained from research conducted directly, while secondary data is data that has been collected from agencies and research [14]. Primary data in this study is data obtained since the sample was taken and tested using an AAS tool so that data results were obtained, while secondary data is in the form of scientific publications to support the analysis carried out. The calculation of the heavy metal content of Cr and Ni in the Putri Cempo TPA soil sample was carried out using the formula:

$$Y = mx + C \qquad (1)$$

Information:
y = sample absorbance
m = coefficient of x
c = concentration/ constant

3 Result and Discussion

3.1 Analysis of Heavy Metal Content (Cr and Ni)

3.1.1 Nickel (Ni)

Table 1. Results of Calculation of Standard Series Ni

Order	Concentration (ppm)	Absorbance (mg/L)
Blank	0	0
Standard 1	0.3	0.0186
Standard 2	2.5	0.1106
Standard 3	3.5	0.1484
Standard 4	5	0.2128
Total 0.09808		

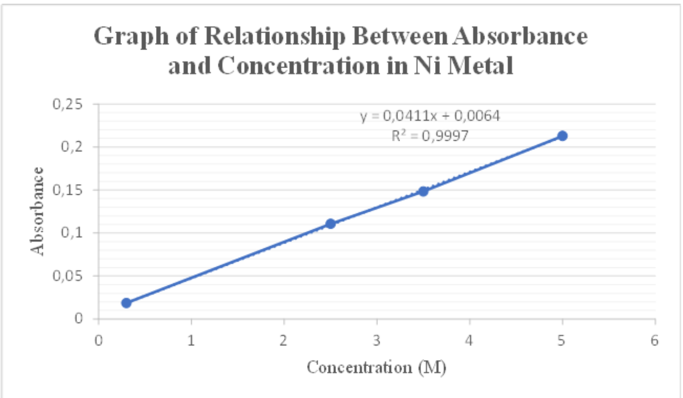

Figure 2. Relationship Between Absorbance and Concentration in Ni Metal

Based on the AAS test that has been carried out, it is known that at a concentration of 0 ppm it has an absorbance of 0, at a concentration of 0.3 ppm it has an absorbance of 0.0186, at a concentration of 2.5 ppm it has an absorbance of 0.1106, at a concentration of 3.5 ppm it has an absorbance of 0.1484, and at a concentration of 5 ppm it has an absorbance of 0.2128. The highest absorbance value is at a concentration of 5 ppm. From the curve, it can also be seen that there are differences in absorbance values at each concentration tested. This absorbance value depends on the level or substance contained in a solution. The higher the level of a substance in a sample, the greater the absorption value because the more molecules absorb light. After calculating using the formula Y = mx + C, it can be seen that the Ni metal content in the Putri Cempo Surakarta TPA soil is 0.94842 mg/L. This high concentration indicates significant heavy metal contamination in the soil, which could have profound effects on soil structure and environmental health. Ni contamination in soil reduces porosity, hindering water and air movement [51]. Additionally, Ni is known as a potent carcinogen that can enter the human body through the consumption of contaminated food or water, skin contact, and inhalation of dust. Previous studies have revealed that Ni exposure can lead to nasal and lung cancer, as well as severe allergic reactions [52].

3.1.2 Chromium (Cr)

Table 2. Results of Standard Series Calculation Cr

Order	Concentration (ppm)	Adsorbance (mg/L)
Blank	0	0
Standard 1	0.2	0.0037
Standard 2	0.5	0.0062
Standard 3	2.5	0.0364
Standard 4	3	0.0419
Amount		**0.01746**

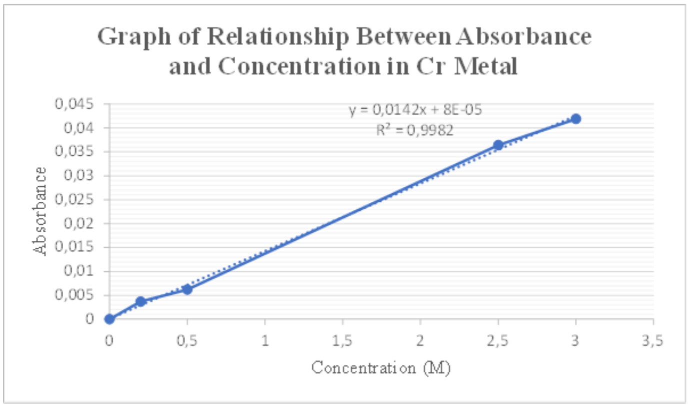

Figure 3. Relationship Between Absorbance and Concentration in Cr Metal

Based on the tests that have been carried out, it is known that at a concentration of 0 ppm it has an absorbance of 0, at a concentration of 0.2 ppm it has an absorbance of 0.0037, at a concentration of 0.5 ppm it has an absorbance of 0.0062, at a concentration of 2.5 ppm it has an absorbance of 0.0364, and at a concentration of 3 ppm it has an absorbance of 0.419. The highest absorbance value is at a concentration of 3 ppm. From the curve, it can also be seen that there are differences in absorbance values at each concentration tested. This absorbance value depends on the level or substance contained in a solution. The higher the level of a substance in a sample, the greater the absorption value because the more molecules absorb light. After calculating using the formula Y = mx + C, it can be seen that the Cr metal content in the Putri Cempo Surakarta TPA soil is 1.2279 mg/L, far exceeding the SNI threshold (0.5 µg/g). Cr in its hexavalent form (Cr^{6+}) is highly toxic and carcinogenic, and exposure to high amounts can cause health issues such as bronchial asthma, lung cancer, and genotoxicity [53]. Beyond human health risks, Cr affects soil microorganism activity, reducing soil fertility and impacting crop quality in contaminated agricultural areas [54]. Therefore, the presence of Cr in high concentrations at the Putri Cempo Landfill requires immediate intervention to prevent further environmental damage.

3.2 Conformity of Cr and Ni with SNI

Table 3. Results of Cr and Ni Content Calculations

Parameter	Y (Abs)	m	X (mg/L)	C
Chromium (Cr)	0.0174	0.01417	1,2279	0
Nickel (Ni)	0.0371	0.04207	0.94842	0.0028

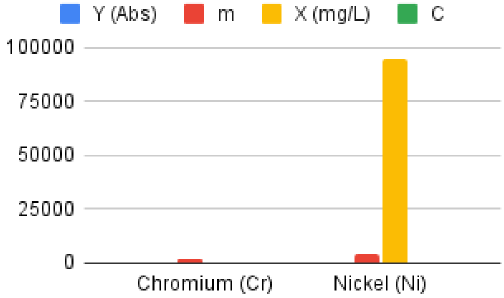

Figure 4. Calculations of Cr and Ni Content

Table 4. Threshold Limit Value (NAB) of Heavy Metals in Sediment/Soil (National Standardization Agency - SNI, 2004)

Heavy metal	Unit	Threshold Limit Value
Lead (Pb)	µg/g	0.07
Cadmium (Cd)	µg/g	0.01
Copper (Cu)	µg/g	0.04
Chromium (Cr)	µg/g	0.5
Nickel (Ni)	µg/g	0.31
Manganese (Mn)	µg/g	0.15
Zinc (Zn)	µg/g	0.06

Table 3 shows that the Cr metal content in soil samples at Putri Cempo Landfill is 1.2279 mg/L. This figure has exceeded the national standardization limit set in SNI 2004 concerning the Threshold Limit Value (NAB) of Heavy Metals in Sediment/Soil (Table 4), which is 0.5 µg/g. From the table, it was also found that the Ni metal content in soil samples at Putri Cempo Landfill was 0.94842 mg/L. This figure has also exceeded the national standardization limit as set by SNI 2004 concerning the Threshold Limit Value (NAB) of Heavy Metals in Sediment/Soil, which is 0.31 µg/g. From the tests carried out, it was proven that the soil samples taken from Putri Cempo Landfill were contaminated with heavy metals.

3.3 Effect of Cr and Ni in Soil Pollution

In recent years, the presence of heavy metals in the soil has become a serious problem because the content of heavy metals such as Cu, Pb, Cd, Cr and Ni in the soil in high concentrations can be harmful to living things, and can harm the activity of several types of enzymes in the soil [15]. Soil is one part of the resources or land that is a place of shelter for living things and plants. The characteristics of the soil can vary from one location to another. These characteristics include physical, chemical, and biological characteristics [16]. The content of heavy metals such as Cr and Ni in the soil can change the physical properties of the soil so that the characteristics of the soil become denser and reduce porosity which will hamper the movement of water and air in the soil. Soil pollution by heavy metals in wet subtropical and dry subtropical regions can cause a decrease in the quality of soil biological parameters. Changes in the biological state of a soil depend on several things, namely the properties of the soil itself, the concentration in the soil and the nature of the pollutant. In some cases, the stimulating effect of heavy metals on soil biological properties is noteworthy especially at 100 mg of metal per kg of soil. This phenomenon is known as hormezis (a dose-response phenomenon to xenobiotics or other stressors characterized by low-dose stimulation) in ecotoxicology. Contamination of soil by heavy metals in the soil can worsen biological conditions such as the number of microorganisms, enzyme activity, and indicators of plant growth and development will reduced. The degree of change in soil biological indicators depends on the nature of pollutants and their concentration in the soil, as well as the genetic properties of the soil. In the soil, as well as the genetic properties of the soil itself, which determine its resistance to pollution [56]. Heavy metals that become pollutants in the soil can come from various sources such as fertilizers, pesticides, organic and inorganic materials, waste residues, and activated sludge. The entry of heavy metals into the soil is one of the most dangerous soil pollutants because it has toxic, carcinogenic, bioaccumulation, and biomagnification properties [17]. The impact of soil pollution from heavy metals is that if it accumulates in the soil in amounts that exceed the threshold, it can affect soil fertility, have toxic properties, and can have adverse effects on human health [18].

Heavy metals in the soil are resistant, not easily decomposed, and can affect the soil environment and the surrounding environment. Heavy metals can persist in the soil for a long time and will affect the quality of the soil, in addition, heavy metals also cause biotoxicity and can change the activity of microorganisms in the soil. Soil that has been contaminated by heavy metals will be very detrimental because it will change the structure and activity of microorganisms so that the higher the heavy metal content in the soil, the lower its fertility will be [19]. So if heavy metals contaminate the land area in the agricultural sector, it will result in a decrease in plant quality and even a decrease in yields. In addition, the content of heavy metals such as Cr and Ni in the soil can cause poisoning of non-target organisms, especially in soil biota, and can be carried up the food chain so that it will harm humans [20]. Soils with acid conditions (pH < 5.5) are utilized to increase soybean production, but this type of soil can cause problems in crop production mainly because soil pH will affect nutrient availability and the level of heavy metal toxicity makes acid soils often lack essential nutrients. Low pH levels can be a limiting factor in the production and nodulation function of soybean plants due to the toxicity effects of Al and Fe ions. Heavy metal elements such as Cu, Zn, and Fe in low concentrations are necessary for plant growth but can be harmful to plants when in higher concentrations. Toxicity is caused by the imbalance of nutrient uptake in plants against the solubility of heavy metals from the soil. Heavy metals can also be a factor inhibiting soybean seed germination. The pH level of heavy metal Fe affects plant growth variables and seed variety characteristics. However, there was no significant interaction between pH and soybean seed varieties in most variables. The interaction between pH and soybean varieties was only found in the dry weight variable with seed hypocotyls. The effect of pH level and Fe heavy metal content on soybean seed viability variables were radicle emergence, seed germination, germination speed, vigor index, hypocotyl length, root length, and root dry weight of normal seedlings and percentage of abnormal seedlings. Heavy metal Fe affects the soybean germination process. The toxicity of Fe heavy metals is stronger in solutions with lower pH. The impact of Fe heavy metal on the soybean germination process can be seen from the beginning of germination, which is characterized by the emergence of radicle or radicle protrusion from the seed. Soybeans can grow in soil containing heavy metal Fe if the soil pH is in the range of 6-7. Soybean varieties affect seed resistance to the presence of heavy metal Fe where Anjasmoro, Deja, Grobogan, and Dega are varieties that consistently show resistance or adapt to the presence of heavy metal Fe [57]. Water used in daily life has the potential to contain Ni metal compounds, so proper use according to water classification needs to be done to prevent impacts on humans and other living creatures [55].

3.4 Impact of Heavy Metals Cr and Ni on Human Health

The presence of heavy metals such as chromium (Cr) and nickel (Ni) in the environment has a serious impact on human health, especially for people living around final disposal areas (TPA) such as TPA Putri Cempo. The presence of these metals in various oxidation states affects their mobility and toxicity in the environment. According to [21], most heavy metals contain hazardous compounds such as *polychlorinated biphenyls* (PCBs), *tetrabromobisphenol A* (TBBPA), and *polybrominated bipheny* l (PBB) which have adverse effects on plants, microbes, and humans. Nickel and chromium, especially in the hexavalent form (Cr^{6+}), can come from industrial waste that is not managed effectively. In addition, the accumulation of heavy metals in the soil is caused by a number of factors, including transportation, waste accumulation, use of fertilizers and pesticides, waste irrigation, and industrial emissions [22], increased concentrations of Cr and Ni in the soil can pose various health risks to exposed residents.

Research conducted by [23], has proven that heavy metals with contamination sources from waste, agriculture, urban waste, and industry can increase the risk of cancer, namely in the order Cd>Ni>Cr>As. Meanwhile, [24] stated that the heavy metal Cr has the potential to cause carcinogenic health problems. Chromium in the form of Cr^{6+} has highly toxic and carcinogenic properties. It is easily dissolved in water and can seep rapidly through soil and groundwater, increasing the risk of human exposure. Fadhila and Purwanti [25] state that Cr can cause various health problems such as bronchial asthma, lung cancer, nasal ulcers, skin allergies, carcinogenicity, and genotoxicity. To avoid the adverse effects of Cr, the World Health Organization (WHO) has determined that the Cr value must be below 0.05 mg/L.

Nickel is a major human carcinogen and can enter through the respiratory tract, digestive system, and skin. Nickel will attack human organs such as the kidneys and lungs [26]. Nickel also has serious impacts on human health, especially if exposed to high concentrations. Nickel can enter the human body through dust particles, skin contact, or consumption of contaminated food and water. Human exposure to nickel can cause nasal and lung cancer. In addition, other harmful effects are carcinogenesis and allergies because nickel has been identified as a strong allergen that often causes allergies in many exposed humans [27]. Heavy metals Cr, Pb, and Ni can increase exposure to *Cancer incidence risk* or lifetime risk of cancer with a value of Ni>Cr>Pb [28]. In addition to having a direct impact on human health, the presence of heavy metals Cr and Ni can also affect public health as a whole. Many heavy metals have been shown to directly modify and/or damage DNA by forming DNA adducts that cause chromosome damage [29]. Heavy metals that enter human tissues and organs can affect the central nervous system and can cause other diseases [30]. The toxicity produced by heavy metals varies depending on their exposure to public health [20]. Children and the elderly with weak immune systems are particularly susceptible to the harmful effects of these heavy metals. The risk of this hazard can be exacerbated if adequate awareness and preventive measures are still lacking. In addition, inefficient waste management and weak environmental quality monitoring can worsen soil and water pollution, increasing the risk of heavy metal exposure for residents.

3.5 Recommended Strategies to Reduce Cr and Ni Contamination

Recommended strategies to reduce Cr and Ni contamination in the soil around the Putri Cempo TPA, Surakarta are raising public awareness and implementing preventive measures are crucial in addressing the health impacts caused by exposure to heavy metals such as chromium (Cr) and nickel (Ni) around the Putri Cempo Landfill, Surakarta. Providing widespread education, particularly to local communities, on the dangers of heavy metals and ways to minimize exposure through skin contact, inhalation, and the consumption of contaminated food or water should be a top priority. These efforts can help reduce the risk of various health issues. Improved management of industrial and domestic waste is also necessary to mitigate sources of Cr and Ni contamination in the landfill vicinity. Employing eco-friendly technologies and implementing strict monitoring of waste output can reduce the amount of heavy metals entering the environment, thereby preventing their accumulation in the soil and water around the Putri Cempo Landfill. Additionally, continuous monitoring of soil and water quality is essential to assess pollution or contamination levels and evaluate the effectiveness of implemented mitigation measures. This monitoring data will support the evaluation of the success of environmental management efforts related to waste and help determine whether adjustments or improvements to existing strategies are needed.

The application of soil remediation technology is a potential solution to reduce heavy metal contamination in soil [31]. Methods of remediation that can be employed to reduce chromium (Cr) contamination in soil include bioremediation and phytoremediation. Bioremediation is a process that utilizes microbes to remove or neutralize pollutants in soil and water. This method aims to restore contaminated environments with the help of bacteria and microbes [34]. Fungi microbes efficient in reducing Cr concentrations in soil include *Penicillium oxalicum* SL2, with a capability of reducing Cr concentrations by 100% [39], and *Saccharomyces cerevisiae*, which can reduce Cr concentrations by 99.6% [37]. Additionally, bacterial microbes efficient in lowering Cr concentrations in soil are *Bacillus subtilis* PAW3, capable of reducing Cr by 100% [35]; *Staphylococcus aureus* strain K1, with a reduction efficiency of 99% [38]; and *Enterobacter cloacae* strain CTWI-06, which can reduce Cr by 94% [33]. Phytoremediation, on the other hand, is a decontamination method that harnesses the role of plants [40]. This technique is environmentally friendly and effective in restoring contaminated soil without harming its fertility or biodiversity [41]. Phytoremediation employs plants to extract (phytoextraction), immobilize (phytostabilization), or volatilize (phytovolatilization) toxic metals [42]. *Helianthus annuus* (sunflower), through phytoextraction, achieves a Cr removal efficiency of 97% and an adsorption capacity of 20 mg kg^{-1} [32]. Similarly, *Ailanthus altissima* (tree of heaven), using phytoextraction, exhibits a Cr removal efficiency of 56% and an adsorption capacity of 358 mg kg^{-1} [36].

The phytoremediation method can also be employed to reduce Ni contamination in soil. Several organisms have proven effective in nickel biosorption, including *Bacillus cereus* [50], *Saccharomyces cerevisiae* [48], and the filamentous fungi *Trichoderma atroviride* strain F6 [49]. Additionally, research conducted by Roccotiello et al. [43] revealed that the leaves of *Alyssoides utriculata*, a Mediterranean plant, possess hyperaccumulator properties for nickel (Ni), capable of absorbing Ni at extremely high concentrations exceeding 1.0 g/kg. This ability makes the plant a promising candidate for phytoremediation, particularly for phytoextraction of nickel a process that recovers nickel from soil. The plant can also be utilized to remediate land contaminated by nickel, providing an environmentally friendly solution to heavy metal pollution. Recent studies have recommended biochar as a promising eco-friendly remediation material due to its unique surface characteristics and its inorganic and organic composition [47]. Specifically, biochar can reduce the mobility and phytoavailability of Ni in soil [44]. Several studies indicate that biochar has a high potential for immobilizing Ni in soil compared to conventional soil amendments such as rocks, lime, organoclays, bentonite, zeolite, activated carbon, and nano-fertilizers [46]. In a field study, hardwood biochar produced at 600°C and applied to soil at rates of 0.5–2% demonstrated up to 200% greater Ni immobilization efficiency compared to the control, three years after biochar application [45].

This study has several limitations that could potentially enhance the comprehensiveness of the discussion, particularly in terms of analytical methodology and environmental factors. The analytical method used in this study focuses solely on measuring Cr and Ni, which may overlook the potential contamination by other heavy metals that could also pose risks to human health and the environment. Additionally, this study does not consider other environmental factors that might influence contamination levels, such as rainfall, soil type, and human activities around the study area. Despite these limitations, this research is expected to contribute to an initial understanding of the issues being investigated.

4 Conclusion

The current concentration of heavy metals in the soil at the Putri Cempo Landfill, Surakarta, particularly chromium (Cr) and nickel (Ni), has exceeded the quality standard limits set by SNI:2004. The concentrations of Cr and Ni pose serious health risks, especially to communities living near the landfill. Exposure to Ni can lead to nasal and lung cancer, as well as allergies due to its strong allergenic properties. Ni can enter the body through dust, skin contact, or the consumption of contaminated food and water. Cr, especially in its hexavalent form (Cr^{6+}), is highly toxic and carcinogenic, potentially causing bronchial asthma, lung cancer, nasal ulceration, skin allergies, and genotoxicity. These two heavy metals increase the risk of cancer, with children and the elderly—whose immune systems are more vulnerable—being at the greatest risk of their effects.

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