Analysis of heavy metal Zn and Ni content in well water of residents around putri cempo landfill

Raja Susatio*, Siti* Rachmawati*, *Ardita Ayu* Wulandari*, Marcella Paramitha Susilo* Dewi*,*
Muhammad Hafiz*, Nisrina Hasna* Fadhila, and *Salsabila Putri* Damayanti

Departement of Environmental Science, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Surakarta 57126, Indonesia

Abstract. The Putri Cempo Final Processing Site (TPA) in Surakarta has the potential to pollute the surrounding environment due to its open dumping system, which produces leachate containing heavy metals. This study aims to analyze the concentrations of heavy metals zinc (Zn) and nickel (Ni) in monitoring well water around the TPA. Sampling was conducted in March 2025 using Atomic Absorption Spectrophotometry (AAS) testing methods in accordance with SNI standards.he analysis showed that Zn concentration reached 3.2825 mg/L and Ni was 0.1512 mg/L, both exceeding the clean water quality standards set by Government Regulation No. 82 of 2001 (0.05 mg/L for Zn and 0.02 mg/L for Ni).. This condition is compounded by environmental parameters such as low pH (3.84) and high ORP (499 mV) further increased metal mobility, posing health and ecological risks. Climate change, particularly increased rainfall and extreme weather, is likely to intensify leachate flow and accelerate heavy metal transport into groundwater. Regular monitoring and remediation technologies such as phytoremediation and adsorption are recommended to reduce contamination.

1 Introduction

Population growth and urbanization lead to an increase in the volume of waste, which, if not managed properly, can negatively impact the environment because the growing population generates more household and industrial waste that must be managed and disposed of. Final Disposal Sites (TPA), as the final stage of waste management, have the potential to pollute the environment through the release of leachate containing heavy metals such as cadmium, chromium, mercury, copper, zinc, lead, and arsenic, which may infiltrate surrounding soil and groundwater [1]. The Putri Cempo Final Processing Site serves as the primary waste processing center for the Surakarta City area. Operating since 1980 on approximately 17 hectares of land originally intended for 20 years of use, it has now functioned for more than 30 years. As a result, the Putri Cempo facility faces serious waste management challenges, particularly due to its inability to accommodate waste generated across the city's transfer stations (WTS). The landfill currently receives around 265 tons of waste per day, leading to overcapacity. Social and environmental pressures further aggravate the situation as the

* Corresponding author: siti.rachmawati@staff.uns.ac.id

accumulation of waste contributes to environmental degradation and contamination of surrounding areas [2]. This issue is intensified by the continued use of an open dumping system, in which waste is disposed of without adequate engineering treatment. Such a system allows leachate to infiltrate and pollute groundwater and surface water in the surrounding hydrological network [3].

Leachate contains various chemical and inorganic compounds, including harmful heavy metals. Heavy metals are toxic to living organisms because they are chemical substances with high atomic weight and specific gravity. Zinc (Zn) and nickel (Ni) are among the heavy metals frequently found in mixed municipal solid waste such as batteries, cans, and electronic components that are disposed of without proper sorting. These metals dissolve easily in leachate and may migrate into the surrounding soil and water, increasing the potential for contamination. At elevated concentrations, heavy metals can be toxic and bioaccumulate within organisms. Leachate-borne Zn and Ni thus pose contamination risks to nearby rivers and residents’ wells, especially as increasing waste volumes intensify leachate production. Climate change further worsens this condition, as extreme rainfall and rising temperatures can increase leachate generation and accelerate heavy metal mobility. Heavy metals such as Zn and Ni are hazardous environmental contaminants with serious ecological and health impacts [4]. Excessive Zn accumulation in plants may disrupt photosynthesis and biomass development, while Ni originating from industrial or electronic waste is highly mobile in water-rich or acidic environments. Ultrafine Zn particles may induce oxidative stress in human lung cells, and even low concentrations of Ni are associated with carcinogenic and non-carcinogenic health risks [5]. These environmental and health risks are anticipated to intensify as climate-related changes exacerbate runoff and infiltration processes that enhance the movement of heavy metals through the environment.

Most previous studies in the Putri Cempo landfill area have focused on heavy metal contamination in soil, surface water, or river sediments, while Zn and Ni contamination in groundwater particularly in residents’ wells has not been comprehensively examined. Groundwater is a primary source of daily water use for nearby communities; therefore, limited assessment of these two metals presents a significant research gap. Previous investigations have also tended to emphasize other metals, even though Zn and Ni are equally prevalent in municipal solid waste and exhibit high mobility under leachate-rich conditions. Due to this lack of focused analysis, the actual exposure risk faced by local residents cannot be accurately determined. There is thus a clear need for research specifically evaluating Zn and Ni in groundwater around the landfill. The novelty of this study lies in providing a direct and focused assessment of Zn and Ni concentrations in monitoring wells surrounding the Putri Cempo landfill, offering new insight into their behavior under current landfill conditions and hydrological pressures influenced by climate variability. Water quality testing of wells around the landfill was conducted because many residents still rely on groundwater for their daily needs. The Putri Cempo landfill poses a risk of environmental contamination, particularly through leachate infiltration into groundwater sources used by the community [6]. Anthropogenic activities around waste disposal sites may also affect air quality. Contaminated well water can carry heavy metals, pathogenic microorganisms, and toxic substances originating from leachate. Exposure to heavy metals may result in systemic or carcinogenic health effects, while microorganisms such as *Escherichia coli* further increase health risks [7]. Therefore, laboratory testing of groundwater quality is essential as a preventive measure to safeguard public health and support the formulation of environmental protection policies. The main objective of this study is to analyze the concentrations of Zn and Ni in groundwater around the Putri Cempo landfill and assess their potential impacts on environmental quality and public health.

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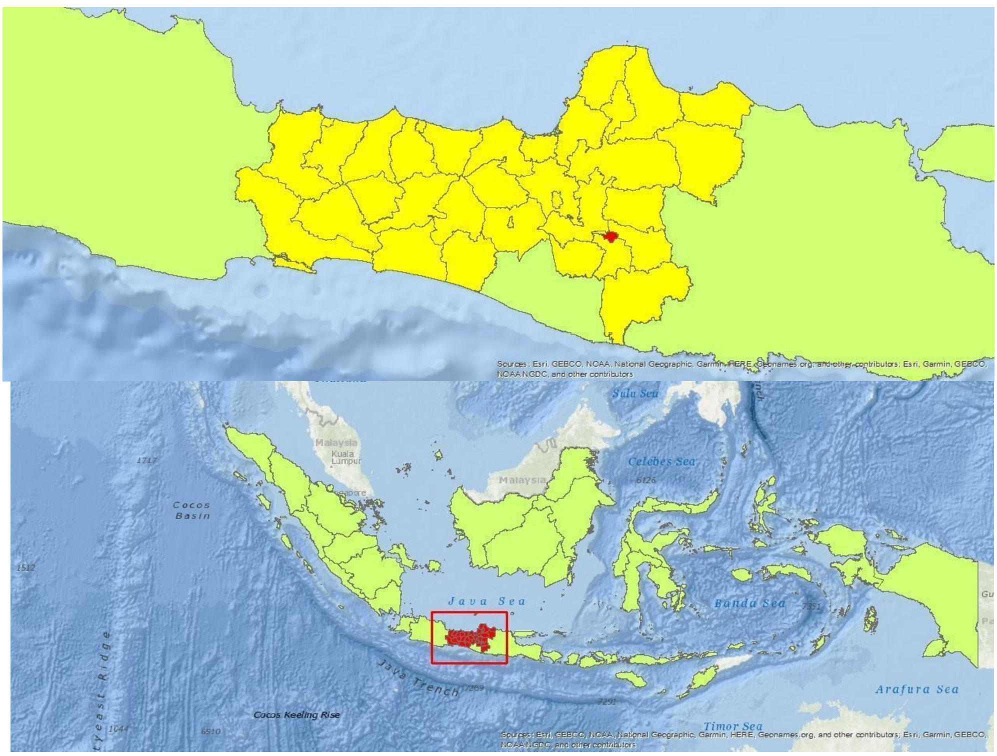
2 Data and methods

2.1 Study area

This research was conducted in March 2025 in the area surrounding the Monitoring Well of the Putri Cempo Final Disposal Site (TPA), located in Mojosongo Subdistrict, Jebres District, Surakarta City, Central Java (Coordinates: -7.5339517, 110.8590051). Data collection was carried out through groundwater sampling from the monitoring well located around the landfill area to analyze the content of heavy metals, particularly zinc (Zn) and nickel (Ni). This location was chosen due to its direct proximity to the landfill site, which poses a high potential for heavy metal contamination as a result of leachate processes. Monitoring the heavy metal content in this monitoring well is important to evaluate potential environmental and public health risks for the communities living around the Putri Cempo landfill, as well as to serve as a basis for pollution management and mitigation in the area (Fig. 1).



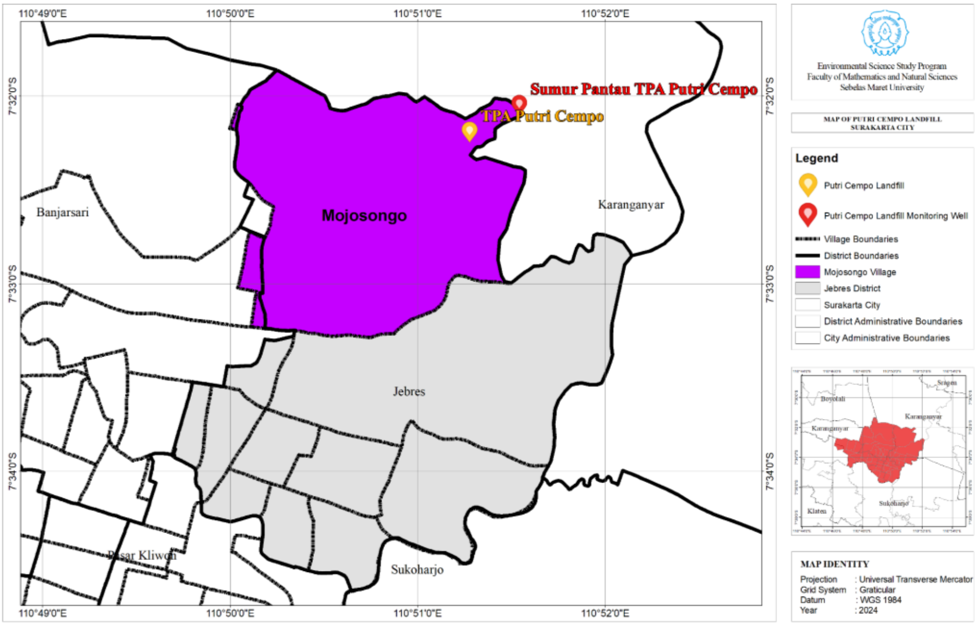


Fig. 1. Map of the monitoring well research area at the Putri Cempo Final Disposal Site (TPA), located in Mojosongo Subdistrict, Jebres District, Surakarta City, Central Java (Coordinates: -7.5339517, 110.8590051)

2.2 Tools and Materials

The tools and materials used in this study consisted of various standard laboratory equipment that supported the process of preparing, collecting, and analyzing water samples. The tools used included 250 mL Erlenmeyer flasks, 25 mL and 50 mL measuring cups, 1 mL and 5 mL measuring pipettes, and droppers for precise addition of reagents. Additionally, reaction tubes, beakers, glass funnels, and 100 mL glass bottles were used as reaction vessels or storage containers. For evaporation or heating of solutions, a stove or hotplate was used. In the process of diluting and mixing solutions, various sizes of measuring flasks are used, namely 5 mL, 10 mL, 50 mL, and 1000 mL, as well as 350 mL sample bottles as the main containers for water collection. The chemicals used include perchloric acid solution ($HClO_4$), nitric acid (HNO_3), distilled water as a solvent, and filter paper to separate solid particles from the solution. All tools and materials are used in accordance with applicable laboratory procedures to ensure the accuracy and validity of the analysis results.

2.3 Procedures

2.3.1 Sampling Techniques

Water sampling in this study followed the guidelines of SNI 8995:2021 on methods for sampling water for physical and chemical testing. This standard was used to ensure that the sampling process was systematic, representative, and scientifically sound. Well water was collected directly using 350 mL glass sample bottles. The use of glass bottles aims to maintain the quality of the water sample for analysis of hazardous compounds, even after long-term storage, without the risk of foreign substances leaching from the container into the sample.

Before use, the bottles were first washed with clean water. Sampling was conducted by directly flowing water from the tap available at the residents' well. The samples were then stored in a cooler at approximately 4 °C or in a low-temperature room and immediately transported to the laboratory for analysis within a maximum of 6 days, in accordance with the guidelines in the standard. The importance of maintaining the temperature and travel time of the sample is very important to pay attention to because it shows that the quality of the water, including the metal content, can change if not stored properly. Before sampling, all measuring equipment such as pH meters and TDS meters were calibrated in advance. Analysis of Zn and Ni metal content was conducted in the laboratory using the AAS (Atomic Absorption Spectrophotometry) method. The sampling and preservation techniques for heavy metal samples followed the practices used in the study in water quality monitoring at wastewater treatment facilities. Meanwhile, to ensure the accuracy of sampling frequency and site design, this study also adapted an approach that suggests a structured approach to monitoring surface and groundwater quality.

2.3.2 Sample Testing Technique

Testing for heavy metal content of zinc (Zn) and nickel (Ni) in groundwater monitoring well samples was carried out in accordance with the Indonesian National Standard (SNI) 6989.84:2019 on methods for testing dissolved and total metals using flame Atomic Absorption Spectrometry (AAS). This method was chosen because of its high sensitivity for detecting metal elements at low concentrations and because it has been nationally standardized for the purposes of water and wastewater quality monitoring.

1. Zn : SNI 6989.7:2009

For the analysis of nickel (Ni) content, the method based on SNI 06-6989.18-2004 was used, which specifically regulates the procedure for Ni testing with flame AAS at a concentration range of 0.3–6.0 mg/L at a wavelength of 232.0 nm. Water samples preserved by adding HNO_3 until pH < 2 were heated until nearly dry, then diluted back to 100 mL with distilled water. A calibration curve was prepared from working solutions with concentrations of 0–6 mg/L derived from a 10 mg/L Ni standard solution. The absorbance results were measured and used to determine Ni concentrations in the samples using linear calibration regression. Although Zn is an essential element, high concentrations can cause metabolic disorders and oxidative stress in aquatic biota. Sources of Zn in groundwater typically originate from leaching of solid waste such as batteries and heavy metals from landfills.

2. Ni : SNI 06-6989.18-2004

Meanwhile, the analysis of zinc (Zn) content was carried out in accordance with SNI 6989.7:2009, which includes procedures for testing total and dissolved Zn using flame AAS at a wavelength of 213.9 nm, with a measurement range of 0.05–2.0 mg/L. For total Zn analysis, homogenized samples were added with concentrated HNO_3 and then heated until the solution became clear. After cooling and diluting to a certain volume, samples were filtered if necessary before measurement. A calibration curve was prepared from a 10 mg/L Zn working solution with a concentration series of 0.1 to 1.5 ppm, pipetted into volumetric flasks, and diluted with a diluent solution to 50 mL. Absorbance was measured to determine concentration using linear regression. Each analytical process was accompanied by blank and matrix spike tests as part of quality control, while considering accuracy and precision parameters based on SNI standards. The analytical results were then used to evaluate the level of heavy metal contamination and potential environmental risks around the Putri Cempo landfill area. The findings of heavy metal contamination at the Putri Cempo landfill are consistent with other studies in Indonesia. Research in the nickel mining areas of Sulawesi has shown that heavy metals such as Ni and Fe can migrate through groundwater for several kilometers if not blocked by impermeable layers [8]. In addition, studies in several regions have shown that chronic exposure to heavy metals in groundwater has serious implications for public health and ecosystem stability.

2.4 Data analysis

The results of testing for heavy metal content of zinc (Zn) and nickel (Ni) were analyzed quantitatively to determine whether the concentrations exceeded the clean water quality standards set by Permenkes No. 32 of 2017. Under this regulation, the maximum permissible levels of heavy metals in water for hygiene and sanitation purposes are 3 mg/L for Zn and 0.2 mg/L for Ni. The metal concentration values obtained from laboratory testing were then compared with these standards to assess the potential health risks to the surrounding community. Quantitative analysis of metal content was conducted using atomic absorption spectrophotometry (AAS), and measurement results were expressed in mg/L. The instrument readings were compared with the previously established calibration curve. The calibration curve was constructed from standard metal solutions with specific concentrations (e.g., 0.1 mg/L, 0.5 mg/L, 1 mg/L, etc.), then plotted in a graph showing the relationship between concentration (x) and absorbance (y). This relationship is analyzed using the linear regression equation: $y = mx + c$, where y is the absorbance value, x is the concentration, m is the slope of the line, and c is the constant (intercept). Once the regression equation is determined, the x value (concentration) can be calculated from the y reading obtained from the instrument. This method is considered quite accurate and is commonly used in testing heavy metals in water which emphasizes the importance of a valid calibration curve in AAS analysis. Additionally, accuracy verification is performed by randomly testing standard solutions to ensure that the resulting values remain within an acceptable deviation range. Once the metal concentration is known, the results are compared with the quality standard. If the concentration exceeds the limit set by the Ministry of Health Regulation, the sample is deemed unsuitable for use in sanitation hygiene activities. In addition, metal concentration data was analyzed descriptively to determine the distribution patterns of contamination around the landfill. This approach was also applied in studies of groundwater quality contaminated with hazardous substances around industrial areas.

3 Results and Discussions

3.1 General Conditions of the Location

The monitoring well of the Putri Cempo Landfill, located in Mojosongo Subdistrict, Jebres District, Surakarta City, is an area with a high potential for heavy metal contamination due to final waste disposal activities. Human activities such as waste management, along with industrial, mining, and agricultural practices, are important sources of heavy metal contamination in soil and water environments [9]. Based on field observations conducted in March 2025, this monitoring well is situated relatively close to the landfill area, making it highly vulnerable to leachate seepage containing heavy metals such as zinc (Zn) and nickel (Ni). The presence of fern vegetation around the wellhead and the partially covered design of the well indicate the possibility of contaminant accumulation in a confined environment. The water sampling process, carried out using laboratory bottles and sensors lowered into the well, demonstrates a scientific approach to obtaining representative water quality data. Monitoring the quality of well water around landfills is crucial, as heavy metals such as Zn and Ni are toxic and can have long-term health impacts on the surrounding community. This is especially true in areas prone to contamination, such as residential areas near landfills. Studies have shown that water and soil in agricultural areas in Central Java contain Zn and Ni contamination from anthropogenic activities, indicating the need for scientifically based mitigation measures.

3.2 Results of Chemical and Physical Parameter Analysis

Table 1. Measurement Values of Physical and Chemical Parameters of Well Water

Parameter	Value	Unit	Classification	Quality Standard
Temp	27.73	°C	physics	±3 °C
pH	7	-	chemistry	6.0 – 9.0
TDS	229	mg/L	physics	≤ 1000 mg/L
DO	10.56	mg/L	chemistry	≥ 4 mg/L

The analysis of heavy metal water quality in this study was based on physical and chemical parameters, including temperature, pH, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), conductivity, and Oxidation-Reduction Potential (ORP). These parameters were measured using a Horiba multimeter. The results indicated a temperature of 27.73°C and a pH of 3.84, a highly acidic condition which can increase the mobility and solubility of heavy metal ions such as Zn2+ and Ni2+.This condition not only threatens human health but also disrupts ecological resilience, particularly soil microbial activity which plays a key role in nutrient cycling and natural remediation processes. Similar to findings in saline-affected soils, environmental stressors such as acidity can suppress microbial diversity and biological function, weakening the ecosystem's ability to naturally buffer contaminants [10]. The TDS was 299 mg/L and conductivity was 461 µS/cm; according to the Ministry of Health Regulation No. 2 of 2023 and SNI 01-3553-2006, both values are still below the quality standard thresholds. The levels of conductivity and TDS can be influenced by temperature, as an increase in water temperature causes ions to become more active, thus raising both values. A high ORP of 499 mV was recorded, indicating a predominantly oxidative environment that can affect the chemical speciation of Ni (e.g., the oxidation of Ni2+ to NiOOH) and reduce the solubility of Zn through oxide formation. Furthermore, a Dissolved Oxygen (DO) level of 10.56 mg/L and 134.5% saturation suggests excessive aeration, which could potentially trigger the precipitation of oxidized metals or the formation of organo-metallic complexes, thereby affecting their bioavailability. The combination of these parameters demonstrates that the well water is highly susceptible to heavy metal contamination, particularly under conditions of low pH and high ORP.

3.3 Heavy Metal Concentration Analysis Results

The concentration of heavy metals in groundwater is an important indicator for assessing the level of environmental pollution, particularly in areas surrounding Landfills (TPA) that are vulnerable to waste contamination. In this study, the main focus is on measuring the levels of zinc (Zn) and nickel (Ni) in monitoring wells around the Putri Cempo Landfill to evaluate the extent to which these two heavy metals accumulate and potentially pose risks to health and the local ecosystem.

3.3.1 Heavy Metal Content (Zn)

Table 2. Results of Heavy Metal Content Analysis

Metal	Concentration (mg/L)	Absorbance (Abs)	Description
Zn	0.0000	-0.0004	Standard
	0.1000	0.0101	Standard
	0.2500	0.0152	Standard
	0.5000	0.0366	Standard
	1.0000	0.0500	Standard
	1.5000	0.0568	Standard
	3.2825	0.1301	Sample (after correction)
Ni	0.0000	-0.0006	Standard
	0.2000	0.0013	Standard
	0.4000	0.0025	Standard
	0.6000	0.0036	Standard
	0.8000	0.0054	Standard
	1.0000	0.0073	Standard
	0.1512	0.0006	Sample (after correction)

Based on the results of laboratory testing using the Atomic Absorption Spectrophotometry (AAS) method, it was found that the concentration of heavy metal zinc (Zn) in the monitoring well water samples at the Putri Cempo landfill reached 3.2825 mg/L. This value was obtained using a linear calibration curve $Y = 0.03827X + 0.0045$, which indicates a high level of accuracy with a coefficient of determination $R^2 = 0.9589$. The calibration curve shown in Fig. 2 illustrates a linear relationship between Zn concentration (mg/L) and absorbance, as indicated by the regression line with the aforementioned R^2 value. This high R^2 value suggests that the AAS method has good reliability and accuracy in measuring Zn levels in water samples. The conformity of the data with the linear curve also strengthens the validity of the laboratory results, making them a strong basis for stating the presence of Zn heavy metal contamination in the study area. This method complies with the provisions of SNI 6989.7:2009, which is used for testing total and dissolved Zn content in water and wastewater. The Zn concentration far exceeds the groundwater quality standard threshold according to the Government Regulation of the Republic of Indonesia No. 82 of 2001, which is 0.05 mg/L, indicating severe pollution caused by waste activities and decomposition at the landfill. This finding shows that well water in the vicinity of the landfill area is no longer fit for consumption and may pose health risks such as kidney disorders, digestive system problems, and chronic toxic effects.

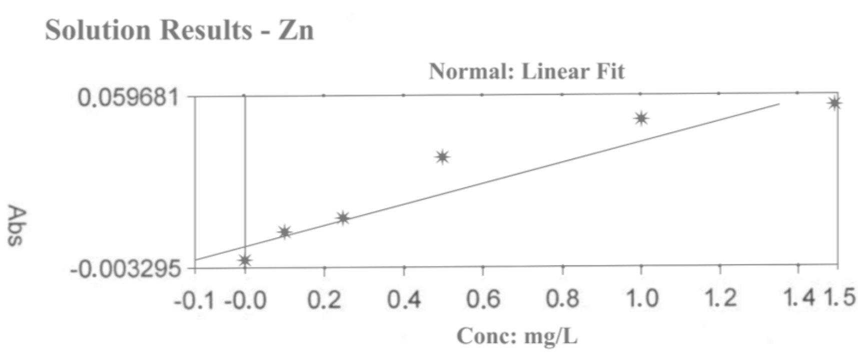


Fig. 2. The Curve of Heavy Metal (Zn) Concentration Analysis Results

A similar phenomenon has also been reported by several national and international studies. As shown in Fig. 2, the calibration curve indicates a linear relationship between Zn concentration and absorbance, confirming the reliability of the measurement results. Zn concentrations in groundwater around the Sukawinatan landfill in Palembang exceeded the threshold limit, reinforcing the findings of contamination caused by leachate. The presence of Zn in the Lowatag River sediment reached 73 mg/kg, indicating the accumulation of heavy metals from human activities. In an international context, Zn metal from human activities can be absorbed into aquatic systems and poses a high risk to biota and human health. In addition, it was noted that Zn has a high bioavailable fraction in soil, indicating its potential to contaminate groundwater through the percolation process.

3.3.2 Heavy Metal Content (Ni)

Based on laboratory testing using the Atomic Absorption Spectrophotometry (AAS) method, the concentration of nickel (Ni) in groundwater from a monitoring well at the Putri Cempo landfill was found to be 0.1512 mg/L. This value was obtained from an average absorbance of 0.0006, calculated using the calibration curve equation $Y = 0.00763x - 0.0006$, where Y represents absorbance and X represents concentration. The analytical method demonstrated high accuracy, supported by a strong linear correlation with an R^2 value of 0.9915, while the sample showed a Relative Standard Deviation (RSD) of 16.5%. The measured Ni level of 0.1512 mg/L exceeds the maximum allowable limit of 0.05 mg/L for groundwater quality as defined by the Republic of Indonesia Government Regulation No. 82 of 2001, indicating serious contamination linked to waste decomposition and other activities at the landfill area.

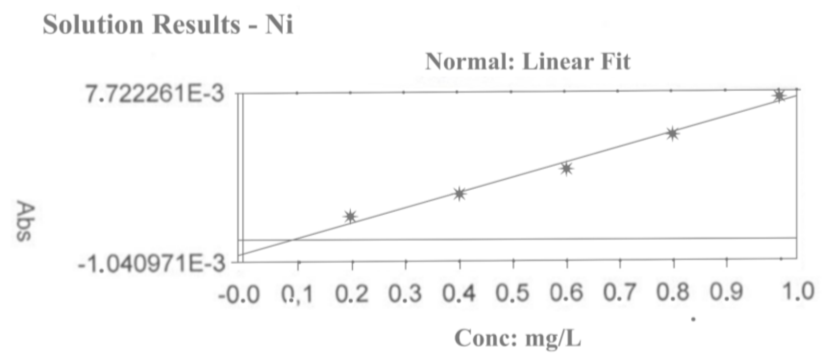


Fig. 3. Heavy Metal Concentration Analysis Results Curve (Ni)

The high concentration of nickel in the groundwater surrounding the Putri Cempo landfill is inextricably linked to potential sources of contamination from the waste disposed at the site. As shown in Fig. 3, the calibration curve demonstrates a strong linear correlation between nickel concentration and absorbance, validating the accuracy of the analytical results. Household waste, effluents from small-scale industries, and particularly electronic waste (e-waste) such as batteries, scrap metal, and other electronic components contain significant amounts of nickel. As this waste accumulates and undergoes decomposition in the landfill, nickel and other heavy metals are gradually released into the environment through leaching by rainwater. Rainwater that percolates through the waste piles generates leachate, a dark-colored liquid containing various hazardous organic and inorganic compounds, including heavy metals like nickel.

3.4 Factors Affecting Zn and Ni Concentrations

High concentrations of zinc (Zn) and nickel (Ni) in the environment are influenced by various interrelated factors, both natural and anthropogenic. Naturally, Zn and Ni content can originate from the weathering of parent rocks rich in these metals. During physical and chemical weathering processes, metallic elements are released into the soil and groundwater. However, significant increases in Zn and Ni concentrations are generally more often caused by anthropogenic activities, such as mining and metal smelting, industrial waste disposal, and fuel combustion. Emissions from these processes can release heavy metals into the atmosphere, which then settle on the soil surface and water bodies. In the agricultural sector, the use of inorganic fertilizers, pesticides, and domestic waste containing heavy metals also contributes to the accumulation of Zn and Ni in the soil, which can then be carried into water systems through surface runoff. One example of heavy metal accumulation due to anthropogenic activities can be found at the Putri Cempo landfill in Surakarta. As the main landfill in the region, this landfill receives solid waste from various sources, including household waste, industrial waste, and market waste. Studies conducted in this area show that the soil around the landfill site contains relatively high concentrations of Zn and Ni, particularly in areas close to waste piles and leachate channels. These heavy metal concentrations have the potential to contaminate groundwater and surface water in the surrounding area, as well as pose risks to ecosystems and public health if not managed properly. Additionally, the characteristics of the soil around the landfill influence the movement and bioavailability of heavy metals. For example, the low pH of the soil and the fluctuating organic matter content from waste decomposition can increase the solubility and movement of Zn and Ni in the soil. Soil texture and cation exchange capacity (CEC) also play a role in the soil's ability to bind or release these metals. Under such conditions, heavy metals can become more available to plants or soil organisms, thereby increasing the risk of accumulation in the food chain and the potential toxicity to living organisms.

3.5 The Impact and Dangers of Heavy Metals Zn and Ni

Water well contamination by heavy metals, particularly zinc (Zn) and nickel (Ni), is a serious issue that can threaten human health and the environment if concentrations exceed quality standards. Long-term exposure to excessive Zn can cause gastrointestinal disorders, such as nausea, stomach cramps, and diarrhea [11]. Additionally, excessive Zn can disrupt copper (Cu) metabolism, leading to deficiencies in essential minerals and weakening the immune system. Recent studies also indicate that Zn accumulation in the body may cause kidney damage and neurological disorders. Nickel (Ni) is a heavy metal with carcinogenic properties when exposed to over the long term. Ni exposure through drinking water can cause allergic contact dermatitis, respiratory disorders, and an increased risk of lung cancer [12]. Additionally, Ni can trigger oxidative stress that damages liver and kidney cells. Other studies have also found that Ni accumulation in the body can disrupt cardiovascular and endocrine system function. The environmental impacts of Zn and Ni pollution are equally concerning. These metals can accumulate in soil, reducing soil fertility and inhibiting plant growth [13]. Furthermore, bioaccumulation in the food chain can increase the risk of heavy metal poisoning in humans and animals.

The impact of heavy metal pollution such as zinc (Zn) and nickel (Ni) is not only limited to direct human health, but also disrupts the overall balance of the ecosystem. When heavy metals contaminate groundwater and surface water, soil microorganisms that play a crucial role in decomposition and nutrient recycling processes are disrupted. This condition can hinder the decomposition of organic matter and nutrient absorption by plants, leading to a long-term decline in soil fertility. Additionally, heavy metals absorbed by plants enter the food chain and accumulate biologically in the bodies of herbivorous animals and humans. These heavy metals cannot be easily excreted by the body, potentially causing organ damage, immune system disorders, and reduced reproductive function. In the long term, the presence of uncontrolled heavy metals in the environment can lead to land degradation, reduced biodiversity, and increased risks of chronic health issues among communities living near contaminated areas. Therefore, regular monitoring of well water quality, the use of effective filtration systems, and control of industrial pollution sources are crucial steps to prevent adverse effects.

3.6 Recommended strategy and policy

Various strategies have been developed to reduce heavy metal contamination such as zinc (Zn) and nickel (Ni) in groundwater, particularly in well systems that are vulnerable to pollutant infiltration. One conventional approach is chemical remediation, which involves reduction techniques and the use of precipitation agents to convert heavy metals into less soluble and less harmful forms. Since heavy metals cannot be naturally degraded and can accumulate in the environment, routine monitoring of well water quality is essential to prevent adverse health and environmental impacts. Additionally, biological approaches involving microbial activity have proven effective in reducing heavy metal concentrations in situ. On the other hand, adsorption using specific materials, such as apatite-like compounds, demonstrates high efficiency in passively capturing Zn^{2+} and Ni^{2+} ions from groundwater, making it a potential option in natural or artificial filtration systems. Chemical precipitation-based remediation is further enhanced through the application of calcium sulfide, which can stabilize heavy metals by directly forming insoluble precipitates at the contamination site [14].

More environmentally friendly approaches have also been extensively researched, one of which is phytoremediation. This method utilizes certain plants that are capable of absorbing and accumulating heavy metals from soil and water, thereby acting as sustainable natural cleaning agents [15]. Additionally, biosorption using organic waste biomass offers a cost-effective and efficient alternative, particularly for removing heavy metals from groundwater through the active surface binding of biomaterials to metal ions. The combination of these approaches offers significant opportunities for developing efficient, economical, and sustainable integrated remediation systems to address Zn and Ni contamination in well water, particularly in areas prone to heavy metal contamination.

4 Conclusion

Based on the research results, it was identified that the monitoring well water around the Putri Cempo landfill has been contaminated with heavy metals zinc (Zn) and nickel (Ni) with concentrations of 3.2825 mg/L and 0.1512 mg/L, respectively. These values exceed the government-established quality standards, indicating that the groundwater around the landfill area is no longer safe for consumption and daily use. The acidic environmental conditions (pH 3.84) and high oxidation-reduction potential (ORP) exacerbate the solubility and movement of heavy metals into the groundwater. Long-term exposure to these metals can cause serious health impacts such as digestive disorders, kidney problems, skin diseases, and cancer risks, as well as disrupting the local ecosystem balance. Therefore, regular monitoring of groundwater quality is absolutely necessary, accompanied by the implementation of appropriate mitigation strategies such as phytoremediation, biosorption, or chemical treatment to reduce heavy metal levels. Additionally, reforms in the management of the Putri Cempo Landfill are crucial, including the cessation of open dumping systems and the adoption of more environmentally friendly waste management and leachate treatment technologies. Without proper intervention, this contamination will not only impact environmental quality but also threaten the long-term sustainability of communities living near the landfill.

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