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Analysis of heavy metal pollution of iron (Fe) and zinc (Zn) in soil at Putri Cempo Landfill, Indonesia

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Abstract. The correlation between heavy metals and environmental pollution is undeniable. This is due to the presence of various types of heavy metals and an increase in the value of heavy metal content, which directly results in a decrease in soil fertility. This study aims to determine the content of heavy metals Fe and Zn in the soil of Putri Cempo Landfill. Analysis of heavy metal substances Fe and Zn is focused because basically both substances are substances that are commonly found in the soil. The method used to measure Fe and Zn is the Atomic Absorption Spectrometry (AAS) method The parameters tested were Iron (Fe) 0, 0.5, 1, 2, 3, 5 ppm while for Zinc (Zn) 0, 0.05, 0.1, 0.5, 1.5, 2 ppm. The sample was then wet destroyed and then tested. Analysis of the results of the equation of the line on the curve obtained a linear regression of the relationship between absorbance and concentration of the standard Fe solution is y = 0.1431 and x = 4.184173 where y is the absorbance value and x is the Fe content. R2 value 1 (R2 = 0.9992). Linear regression of the relationship between absorbance and concentration of standard Fe solution is y = 0.1431 and x = 4.184173 mg/Kg, where y is the absorbance value and x is the Fe content. Putri Cempo Landfill soil is still below the specified threshold value. Based on these results, the land in TP Putri Cempo is still considered good for use by human activities, agriculture and for ecology.

1 Introduction

Soil is a natural resource that is important for human life and the environment. Soil has an essential role in supporting plant growth, providing habitat for organisms, and playing a role in the nutrient cycle and water cycle [1]. Soil is a substrate consisting of loose minerals and organic matter, which includes three phases: solid, liquid, and gas, which are present on the earth's surface. Formed through a weathering process involving interactions between the lithosphere, atmosphere, hydrosphere, and biosphere, which are habitats for various micro and macro-organisms, plants, and animals [2]. Overall, soil supports human life and

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civilization. Good and fertile soil is soil that has good chemical, physical, and biological properties [3]. Soil with good physical properties will also provide good environmental quality. Fertile soil not only supports plant growth but also plays an important role in maintaining environmental quality. Healthy soil can filter water, neutralize pollutants, and store carbon. However, soil can also be contaminated by various substances that can harm human health and the ecosystem.

One type of contamination that is often of concern is the presence of heavy metals in the soil. Heavy metals are natural substances found in the earth's crust that cannot be broken down or destroyed [4]. The relationship between heavy metals and environmental pollution is undeniable. This relationship is very close because the more varied the types of heavy metals and the higher the heavy metal content, the more soil fertility will decrease. The level of metal toxicity in soil varies and can be categorized as low, medium, and high. Metals with low toxicity levels generally do not cause significant problems. Meanwhile, metals with moderate and high toxicity levels can inhibit plant growth, disrupt the balance of soil microorganisms, and even poison plants [5]. Heavy metals are found in various industrial wastes. The presence of metals in industrial waste is one of the main problems that causes environmental pollution. Heavy metals are an environmental threat that damages the ecosystem [6]. Heavy metal waste disposed of from various industrial locations poses a threat to human health and accumulates in rivers or soil. Heavy metals such as iron (Fe) and zinc (Zn) are elements commonly found in soil and are required in small amounts for various biological processes. Iron and zinc are heavy metals that play an important role in biological processes in plants, animals, and humans, such as enzyme formation, cell division, and other metabolic processes. For example, iron is important for photosynthesis in plants and carries oxygen to humans through hemoglobin. Zinc (Zn), on the other hand, is important for protein synthesis, enzyme activity, and cell growth. However, if the concentration of these metals is too high, it can be toxic and damage living organisms and disrupt the balance of the ecosystem. According to [7], there is an alleged decrease in the availability of the heavy metal iron (Fe) caused by a lack of pollutants. This has the potential to reduce the process of dilution, oxidation or reduction, ion exchange absorption, and reactions with organic substances.

Surakarta City is one of the big cities in Central Java Province which is known as the center of Javanese culture with a long history and a rapidly growing economy. The increasing economic and population growth in this city poses a major challenge in waste management, most of which is handled by the Putri Cempo Final Processing Site (TPA) [8]. Although the regulation stipulates that the TPA must be far from residential areas, in reality, the available land is increasingly limited due to population growth. The Putri Cempo TPA, which has been operating since 1986, is located in Mojosongo Village, Surakarta, with an area of 17 hectares. This TPA is tasked with receiving waste from Surakarta City and its surroundings. However, due to limited land, the residential area that has grown near the TPA directly borders Mojosongo Village (Surakarta) and Plesungan Village (Karanganyar Regency) [9]. Waste management at Putri Cempo Landfill includes various methods such as landfilling, which is the process of piling up waste in a specially designated area. At Putri Cempo Landfill, waste is compacted and piled in a designated landfill area. In addition, recycling is also an important part of waste management at Putri Cempo Landfill. Recyclable waste, such as paper, plastic, glass, and metal, is sorted and reprocessed for reuse [10].

In the landfill (Final Processing Site) Putri Cempo Research related to the content of heavy metals such as iron (Fe) and zinc (Zn) in landfills especially in the Putri Cempo landfill is still very limited. Most of the previous studies focused more on other heavy metals or on different locations. To date, there is no comprehensive study that identifies the level of Fe and Zn contamination in the Putri Cempo landfill specifically., the presence of heavy metals such as iron (Fe) and zinc (Zn) can be found in varying levels, depending on the history of

land use, other human activities that may have occurred in the area. As a final disposal site, Putri Cempo Landfill receives and processes waste from various sources, including industrial, commercial, and domestic. Commercial and domestic waste disposed of to the final processing site (TPA) can pollute soil and groundwater. Industrial waste often contains high concentrations of heavy metals due to manufacturing and material processing processes, while commercial and domestic waste contributes heavy metals through consumer products such as batteries, electronics, and building materials. Heavy metals from this waste can accumulate in the food chain and endanger human and animal health.

This study aims to identify the concentration of heavy metals Fe and Zn in the soil of Putri Cempo Solo Landfill. The results of the test of heavy metals Fe and Zn in the soil of Putri Cempo present a comparison of Iron (Fe) and Zinc (Zn) levels with the threshold set by environmental regulations. The results of this study can be the basis for making the right decisions in the management of Putri Cempo Landfill and preventing more severe environmental pollution.

2 Research Methods

2.1 Time and Location of Research

This research was conducted in April-May. The first stage of this research was conducted on April 20, 2024, at the Putri Cempo Final Processing Site (TPA), Surakarta (Figure 1). The research was conducted using soil samples from the Putri Cempo TPA at one sampling point. The wet destruction process was carried out at the Soil Science Study Program Laboratory, Sebelas Maret University, Surakarta on April 23, 2024. Heavy metal testing using the AAS (*Atomic Absorption Spectrometry*) method was conducted on May 8, 2024, at the chemistry sub-lab of the Sebelas Maret University Laboratory UPT, Surakarta.

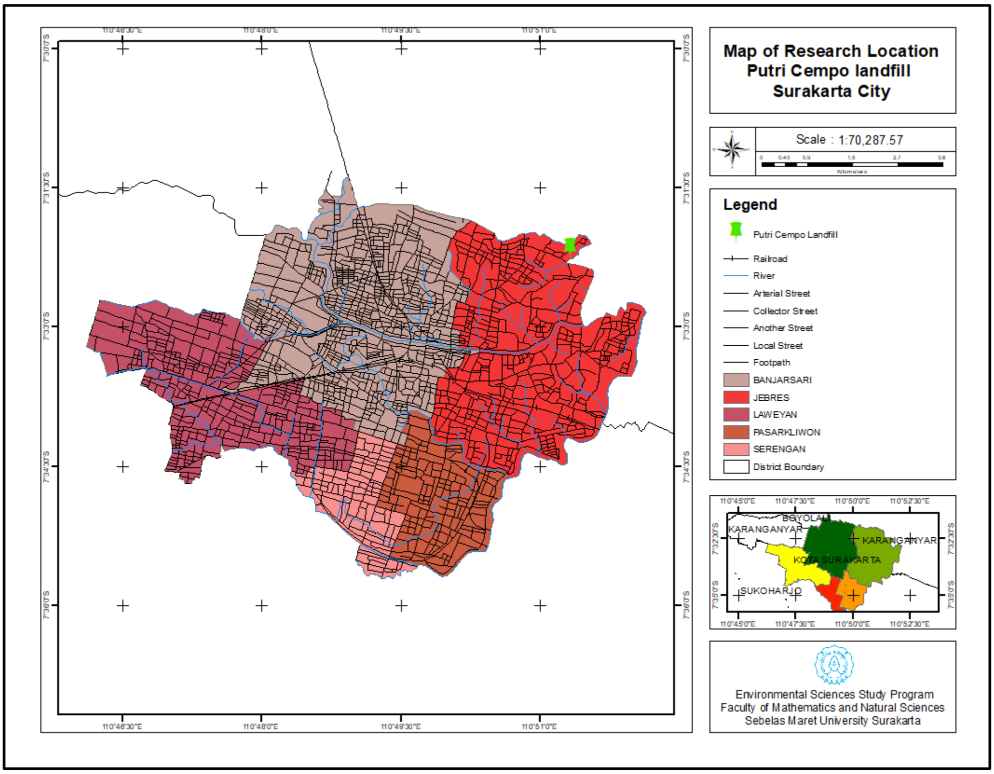

Figure 1. Research Location

2.2 Tools and Materials

The tools used in this study were shovels, plastic containers, 250 mL beakers, 50 mL measuring flasks, 1 mL measuring pipettes, AAS instruments and glass fins. The materials used in this experiment were Putri Cempo TPA soil, aquabides, Fe, and Zn stock solutions of 1000 ppm.

2.3 Field Data Collection

The soil sampling of Putri Cempo Landfill was carried out using a random sampling method at one point in the middle of Putri Cempo Landfill (-7.5359869, 110.8554173). The soil samples of Putri Cempo Landfill were taken using a shovel and stored in a plastic container. The soil taken was disturbed soil that could be taken at a depth of 0-20 cm [11]. Generally, at this depth, it is the layer of soil that is most disturbed due to human activities, such as agriculture and plantations [12]. At the time of sampling, the samples were then dried under sunlight to reduce the water content. The samples were then sieved using a sieve to separate the soil from other solids. The samples were then taken to the laboratory.

2.4 Sample Analysis

Heavy metal testing in this study used *the Atomic Absorption Spectrometry* (AAS) method [13], using the principle of energy absorption using radiation with a certain wavelength by atoms to produce excited electronic energy. The AAS method is a method that has fairly good

selectivity and sensitivity in samples [14]. The parameters tested were Iron (Fe) levels of 0 ppm; 0.5 ppm; 1 ppm; 2 ppm; 3 ppm; 5 ppm while the standard Zinc (Zn) solution covered 0 ppm; 0.05 ppm; 0.1 ppm; 0.5 ppm; 1.5 ppm; 2 ppm. The samples were then subjected to wet destruction and then tested. The samples were then analyzed using qualitative methods using primary and secondary data.

2.5 Data Analysis

This study calculates the levels of heavy metals in samples using linear equations from the results of AAS tests of standard solutions of Iron (Fe) and Zinc (Zn).

3 Results and Discussion

3.1 Fe Content in Putri Cempo Landfill Soil

This study utilized primary data obtained through testing with the *Atomic Absorption Spectrometry* (AAS) method to determine the content of heavy metal Iron (Fe) in the soil at the Putri Cempo Landfill, Solo. The AAS method was chosen because of its principle of using the absorption of energy from radiation with a certain wavelength by atoms, so that it can produce excited electronic energy that can be detected. In this test, the parameters tested included Iron (Fe) levels at concentrations of 0 ppm, 0.5 ppm, 1 ppm, 2 ppm, 3 ppm, and 5 ppm. Based on the test results, absorbance data from the standard Fe solution were obtained, which are presented in table 1 as follows:

Table 1. Fe Test Result Data

	y (abs)	m	x(mg/Kg)	C
Fe	0.1431	0.03475	4.184173	0.0023

From Table 1, a standard calibration curve for Fe metal can be produced which is used to determine the linear regression line equation and the determination coefficient value (R2), as shown in Figure 2.

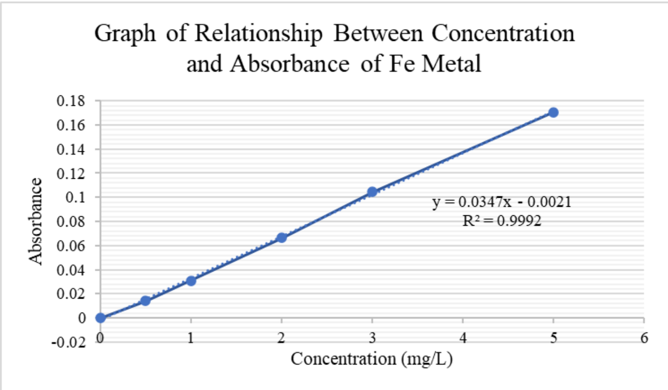

Figure 2. Relationship between Concentration and Absorbance of Fe Metal

The initial stage of this study is sample preparation. The sample preparation process is carried out through the destruction method. Destruction is the process of breaking down compounds into their elements, where organic metal compounds are converted into inorganic metals. This destruction is divided into two methods, namely wet destruction and dry

destruction. In this study, the wet destruction method was used. In the wet destruction process, HNO_3 was used. The addition of HNO_3 serves to prevent precipitation and dissolve the metals contained in the solution. This is because in water, Fe ions will undergo hydrolysis and form solid $Fe(OH)_3$. If precipitation occurs, there will be inaccuracy in the measurement process.

The Fe metal content in the soil was carried out at 1 point in the Putri Cempo TPA area. AAS analysis was carried out by making a calibration curve based on a standard Fe solution with different concentrations. From the calibration curve, a linear regression equation can be obtained that describes the relationship between Fe metal concentration and absorbance. The equation shows a positive relationship between Fe concentration (X) and absorbance value (Y). This means that the higher the Fe concentration, the higher the measured absorbance value. The relationship between concentration and absorbance values can be visualized with a linear relationship graph or a straight line. The regression coefficient shows the magnitude of the change in absorbance value for each change in one unit of Fe concentration. The greater the regression coefficient value, the greater the effect of Fe concentration on the absorbance value [15].

Figure 1. shows the calibration curve for the Fe standard solution. This curve shows a linear relationship, which means that when the Fe concentration increases, the absorbance also increases. This phenomenon is by the Lambert-Beer principle, where absorbance increases with increasing concentration [16]. From the equation of the line on the curve, the linear regression of the relationship between absorbance and the concentration of the Fe standard solution is $y = 0.1431$ and $x = 4.184173$ mg / Kg, where y is the absorbance value and x is the Fe content. The R^2 value in Figure 2. which is close to 1 ($R^2 = 0.9992$) indicates that the linear regression model used can explain almost 100% of the variation in absorbance data caused by variations in Fe metal concentration [17]. A very high R^2 value, such as 0.9992, indicates that in the AAS analysis, the relationship between Fe metal concentration and absorbance is very strong and the linear regression model used is very suitable.

The presence of heavy metal iron (Fe) levels is caused by the accumulation of decomposition of organic and inorganic waste that is buried in the landfill [4]. The decrease in the presence of heavy metal iron (Fe) is influenced by the lack of pollutants that will affect the process of dilution, oxidation or reduction, ion exchange, and reactions with organic substances [7]. The metal content originating from domestic waste that is buried with soil in the area around the Putri Cempo landfill is also based on human waste disposal activities. The high and low content of heavy metal iron (Fe) can also be caused by temperature factors, this factor has an important role in the solubility of iron because it can decompose the degree of solubility of iron metal (Fe). In addition, during the rainy season, a sedimentation process can occur in soil sediments which coincides with the deposition of heavy metals caused by the high density of metals compared to the density of water [18]. At the point of collection, the nearest land area becomes muddier due to the rainy season. This causes the metal content to increase due to the decreasing size of soil sediment particles. The content of heavy metal Fe which has a higher atomic weight will certainly settle faster in the soil. In this case, soil sediment certainly has a relationship between particle size and the content of other organic materials. Soil sediment that has a fine texture will have a higher percentage of organic matter than coarse sediment. This is because coarse sediment has a lower organic content. After all, fine particles do not settle [19].

3.2 Zn Content in Putri Cempo Landfill Soil

In addition to the heavy metal Iron (Fe), this study also analyzed the content of heavy metal Zinc (Zn) in the soil at the Putri Cempo TPA using the Atomic Absorption Spectrometry (AAS) method. AAS was chosen because of its ability to detect metal concentrations in

samples with a high level of sensitivity. In the Zn test, the standard solutions used had concentrations of 0 ppm, 0.05 ppm, 0.1 ppm, 0.5 ppm, 1.5 ppm, and 2 ppm. Primary data from this AAS test provides important information regarding the level of Zn heavy metal pollution at the research location. Based on the test results, absorbance data from the Zn standard solution were obtained, which are presented in table 2 as follows:

Table 2. Zn Test Result Data

	y (abs)	m	x (mg/Kg)	C
Zn	0.212	0.15398	1.278737	0.0151

From Table 2, a standard calibration curve for Zn metal can be produced which is used to determine the linear regression line equation and the determination coefficient value (R2) , as shown in Figure 3.

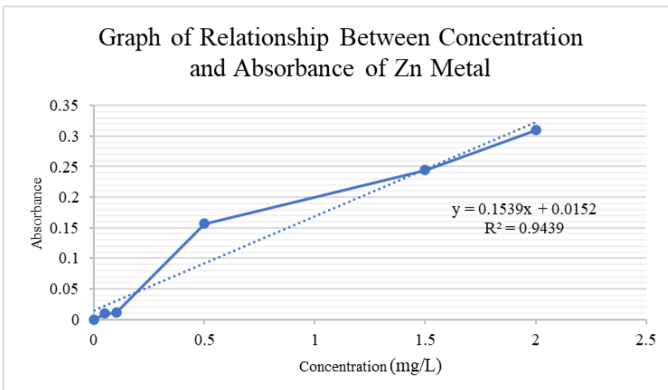

Figure 3. Relationship between Concentration and Absorbance of Zn Metal

The content of zinc (Zn) metal in the soil was carried out at 1 point in the Putri Cempo TPA area. From the graph of zinc (Zn) metal content in the Putri Cempo TPA soil, it can be seen that the Zn content in the soil sample shows a fairly high value, reaching 1,278,737 mg/Kg. When compared to the Zn quality standard for vegetated soil according to Government Regulation No. 101 of 2014, which is 200 mg/kg, the Zn concentration in the Putri Cempo TPA soil is still below the threshold value set. This indicates that the Zn content in the Putri Cempo TPA soil is still safe and has not polluted the environment. The R2 value in Figure 3., namely (R2 = 0.9432), shows that the linear regression model used can explain the correlation relationship between the concentration of metal absorbance data caused by variations in the concentration of Zn metal. Based on the data presented in the graph of the relationship between absorbance and concentration for Zn metal, it can be seen that the higher the concentration of Zn solution, the greater the absorbance read. This is by Lambert-Beer's law which states that the absorbance of a solution is directly proportional to the concentration of the solute.

The presence of heavy metal levels of Zinc (Zn) is influenced by the composition of the sediment. Generally, heavy metal content will tend to increase according to the depth of the soil, this is certainly based on the age of the waste pile. The longer the age of the waste pile, the heavier metal content will follow the groundwater flow and will most likely be stored in the soil layer for a longer time because the layer has a more clayey soil texture and allows seepage in a more horizontal direction [5]. Waste that is buried due to human waste disposal activities will carry the heavy metal content of zinc (Zn) which will be carried by leachate until it enters and spreads into the soil [20] in this case, the high or low concentration of heavy metal content Zn is influenced by how much waste disposal activity is carried out by

the local community. In addition [21] has stated that clay minerals in the soil can absorb Zn. The heavy metal content of Zn is also influenced by soil pH, where the Zn content will automatically decrease if the soil pH increases and Zn will automatically increase if it decreases. The content of the heavy metal Zn is also influenced by several other factors such as organic matter, microbial activity, humidity, climate, and interactions between Zn and micro/macro elements in the soil [22].

However, it should be noted that the results of the Fe and Zn metal tests only reflect a picture at one point in time and one sampling point. The content of heavy metals in a landfill area can fluctuate depending on several factors, such as the time and location of sampling, activities occurring at the landfill, and the type of waste disposed of. Therefore, it is important to conduct regular monitoring and apply it to several locations at the Putri Cempo landfill in order to gain a more holistic understanding of the risk of heavy metal pollution in the area. Not only that, it is also necessary to consider the possibility of *human error* in the sampling process, sample preparation, and laboratory analysis. Although the procedure is standard, factors such as measurement errors, contamination, sample loss, or errors in reading the analysis results can still occur and have the potential to affect the accuracy of the results. Therefore, it is necessary to retest and improve quality control at each stage of the analysis to reduce the possibility of *human error* and ensure more reliable results.

By conducting regular and careful monitoring and testing, the information obtained regarding the level of heavy metal pollution in Putri Cempo Landfill can be used for several purposes, such as evaluating the health risks to humans and the environment exposed to heavy metals, developing effective strategies to control heavy metal pollution with mitigation and cleanup measures, and ensuring sustainable and environmentally friendly landfill management by using the data to design better policies and practices in waste and environmental management. Therefore, careful monitoring and testing not only provide a better understanding of the condition of the landfill, but also help in taking appropriate actions to protect human health and the environment and improve the sustainability of landfill management as a whole.

3.3 Comparison of Results of the Relationship between Concentration and Absorbance of Fe and Zn Metals

Based on the data in tables 1 and 2, there are two types of heavy metals tested, namely Fe (iron) and Zn (zinc), with the relationship between absorbance (y) and concentration (x) recorded. The graph equation for Fe metal shows y (abs) = 0.1431x (mg/Kg) + 0.0023, while for Zn metal, y (abs) = 0.15398x (mg/Kg) + 1.278737. The difference in this equation reflects the different absorbance characteristics between Fe and Zn metals at the same concentration, due to differences in chemical and physical properties between the two such as electronic structure, atomic radius, and ionization energy. In analysis using *Atomic Absorption spectrometry* (AAS), the intensity of metal absorption in the sample is correlated with its concentration. Therefore, the relationship between absorbance and concentration depends on the atomic and absorption properties of each metal. Tables 1 and 2 present the results of Fe and Zn metal tests using AAS, with the slope coefficient (m) and constant (C) of the line equation used to calculate the metal concentration in the sample.

3.4 Relationship Between the Content of Heavy Metals Fe, Zn, and The Content of Other Organic Materials

The soil at the Putri Cempo landfill absorbs water produced by the pile of waste. Waste containing heavy metals is decomposed with liquid waste (leachate). The high content of heavy metal iron (Fe) can be caused by the accumulation of decomposition results of organic

and inorganic waste that is buried in the landfill. Leachate sometimes contains organic compounds and inorganic compounds (heavy metals) commonly called sediment. Heavy metals can cause toxins in the body for a long time [4]. Heavy metals tend to stick to other particles and organic materials. Heavy metals settle at the bottom of the water and combine with other sediments. As a result, the concentration of heavy metals in the sediment is usually higher than in the water itself [23]. The concentration of organic matter is influenced by sediment. Fine-textured sediments can absorb higher organic matter compared to coarse-textured sediments [13]. The atomic weight of heavy metals affects the speed or slowness of a deposit. The greater the atomic weight, the faster it settles into the sediment [25].

3.5 Impact of Fe and Zn Heavy Metal Content on Abiotic, Biotic, and Culture

It is known that heavy metals are one of the elements that are harmful to the environmental ecosystem. Heavy metals have many negative impacts that can damage the environment which can endanger the health of living things. At the Putri Cempo TPA location, the TPA is a place that is very close to residential areas. The presence of various Fe and Zn heavy metal contents in soil sediments will provide various risks that can occur. The content of Fe and Zn heavy metals is generally an essential heavy metal that is needed in low concentrations for living things, but the content of Fe and Zn heavy metals that exceeds capacity or exceeds the maximum limit will pollute the environment and can endanger the health of living things [26]. Soil that contains Fe and Zn heavy metals will have an impact on the groundwater channels that will be used by the local community which can cause a lack of clean water for the local community, the content of Fe and Zn heavy metals also affects the quality of the soil [27] from the local community's residence and becomes polluted, this makes the community more susceptible to disease due to pollution from Fe and Zn heavy metal content. In the quality of local rice field soil, generally the Fe content has essential benefits for plants in certain amounts, but if the concentration of the heavy metal Fe content exceeds the maximum limit, it will hurt plants and even make plants susceptible to producing new plants [28]. Essential elements such as iron (Fe) and zinc (Zn) are needed by plants in certain amounts for healthy growth, with the required iron levels ranging from 50 to 250 ppm, but can be toxic if they exceed 500 [29]. Similar to the heavy metal content of Zn, it is generally an essential heavy metal that is needed in low concentrations for living things, but in high concentrations, it can have a toxic effect on living things.

4 Conclusion

Soil samples from the Putri Cempo landfill showed significant heavy metal content in the form of iron (Fe) and zinc (Zn), each indicating a level of pollution that requires further attention.t This indicates that by Government Regulation No. 101 of 2014, which is 200 mg/kg, the concentration in the soil of Putri Cempo Landfill is still below the threshold value set. These results only reflect conditions at one point in time and one sampling point. Fluctuations in heavy metal content can occur depending on several factors such as the time and location of sampling, activities at the landfill, and the type of waste disposed of. The author does not include recommendations because the results of the study showed that iron (Fe) and zinc (Zn) were still below the threshold value.

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