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Research Article

EVALUATING THE BIOCONCENTRATION FACTORS (BCF) AND ESTIMATED DAILY INTAKE (EDI) OF HEAVY METALS IN LIME PLANTS (*CITRUS AURANTIFOLIA*) IN SMALL SCALE GOLD ORE PROCESSING AREAS

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Abstract
Small-scale gold ore processing areas have become a global concern due to their significant contribution to heavy metal pollution. The residual amalgamation process in these areas leads to the accumulation of heavy metals in the environment, which can bioaccumulate in living organisms. This study focuses on the lime plant (Citrus aurantifolia), commonly found in small-scale gold ore processing areas, particularly in Sukamenang village. The research aims to assess the Bioconcentration Factor (BCF) and Estimated Daily Intake (EDI) of heavy metals in lime plants to evaluate the risk to residents who consume them. Samples were collected using random sampling and analyzed with an Atomic Absorption Spectrophotometer (AAS) and a mercury analyzer. The results indicate that Citrus aurantifolia has a BCF value of less than 1 (<1), classifying it as an excluder plant, effectively preventing heavy metals from entering its upper parts and allowing it to thrive in polluted environments. However, the consumption of these plants poses health risks. The study highlights the Reference Dose (RfD) values for heavy metals: Cu at 4.0 x 10^-2 (0.008), Fe at 0.7, and Hg at 0.0001, as recommended by the United States Environmental Protection Agency (USEPA) in 2011. Heavy metals such as Fe, Cu, and Hg in the lime plants indicate potential adverse health effects due to their toxicity. This research underscores the necessity for monitoring and mitigating heavy metal pollution in small-scale gold ore processing areas to protect public health and the environment.

Keywords: Bioaccumulation, Bioconcentration Factor (BFC), *Estimated Daily Intake* (EDI), Small-Scale Gold Ore Processing

INTRODUCTION

The activities of gold ore mining and processing in small-scale are currently carried out by many people throughout the world, including in the developed and developing countries from Central and South America to Africa, and from Oceania to Asia. This is because the income from these activities are 3 to 5 times higher than the income from forestry, fisheries and agriculture (Tun 2020). However, the profit is inversely proportional to the impact that could occur on the environment around the gold ore processing area. A research in China showed that the average concentration of heavy metals such as Cu, Zn, As, Cd, and Pb in regional agricultural soil was 7 times higher than the permitted threshold value. The results of multivariate statistical analysis showed that heavy metal contamination is caused by small-scale gold ore mining and processing activities (Sun et al. 2018).

The toxicity and non-biodegradability of heavy metals can accumulate in the food chain, including in plants. The accumulation of heavy metals is very dangerous for the environment and human health. As many as 500 types of plants throughout the world have been confirmed as natural hyperaccumulators (Petelka et al. 2019). The presence of heavy metals in the soil will be absorbed by the plants that grow on it. The level of accumulation of heavy metals in plants depends on the soil type, pH level, the humidity, and the micronutrient content, as well as on harvest time (Zwolak et al. 2019). Heavy metals can accumulate in plants through soil and air. Heavy metals that polluted the soil can be absorbed by plants through their roots and vascular systems (Sulaiman and Hamzah 2018). Apart from that, heavy metals in the air can also be deposited and absorbed by the leaves (Shahid et al. 2017).

High level of accumulation of heavy metals in plants can inhibit the plant's ability to produce chlorophyll, increase the plant oxidative stress and weaken the stomata resistance (Sulaiman and Hamzah 2018). Thus, the presence of heavy metals in plants can be an indicator of the presence of heavy metals in the soil and in the air around the plants. All parts of plants such as the leaves, the roots and the fruit can be biomonitors of the presence of heavy metals in the surrounding environment (Aricak et al. 2020). Plants that have an accumulated levels of mercury (Hg) will be dangerous for other living organisms. One living organism that can accumulate heavy metals is lime. Heavy metals accumulate in the body can have negative impacts on the health. Estimated Daily Intake (EDI) can be used to calculate the estimated intake of a contaminant such as heavy metals in the human body. The EDI value is greatly influenced by two factors, which are the heavy metals concentration in the organism as well as the body weight of the respondent (human) (Javed and Usmani 2016). To determine the level of risk on whether heavy metals have accumulated in an organism's body, the RfD value of a heavy metal is used. For heavy metal like mercury (Hg) the RfD value is 0.0001 mg/kg/day (River 2023)(Traven et al. 2023)(Wong, Roberts, and Neal 2022).

According to Javed and Usmani (2016), if the ratio of EDI of heavy metals to RfD is the same or less than, the risk of the heavy metal to health is considered as minimal. If the EDI is > 1–5 times the RfD of the metal itself, then the risk is considered as low. If the EDI is > 5–10 times the RfD the risk is considered as moderate, and if the EDI is > 10 times the RfD then the risk is considered as high. The BCF value and EDI value in this study were gathered from the lime plants (*Citrus aurantifolia*) that were planted in Sukamenang Village. Sukamenang Village is known for its small-scale gold mining which has been around for 30 years. Based on the results of field observations, the lime plant (*Citrus aurantifolia*) is one of the plants that grows a lot in the residents' yards, where the majority of the residents' houses have a small-scale gold ore mill. According to the data from the North Musi Rawas Regency Government (2019), the majority of Sukamenang Village residents use their land as lime plantations. The lime trees have a height of 2-5 meters and has been used by the local community for approximately 10 years. The community consumed the fruit as well as the leaves for their daily needs. However, the lime plants were located not far from the gold ore processing location which produced a dangerous hazard for the environment, namely heavy metal such as mercury (Hg).

The number of lime plants planted in Sukamenang Village is also influenced by the condition of the soil. The results of a review on the soil texture in Sukamenang Village showed that the soil present in the village was inceptisol soil with a gray or dark brown color and it has the characteristics of dusty clay with a crumbly soil structure. Inceptisol soil has a low phosphorus level while having a high level of aluminum and iron. The acidity contained in this type of soil is between 5.0 to 7.0 with a saturation level of 0-72 percent, making it a soil that has a moderate acidity level. Inceptisol soil type is not suitable for agricultural use. However, it is suitable for plantation crops (Nasir and Hilda 2018). This is one of the factors why lime plants can continue to survive in small-scale gold ore processing areas even though they accumulated heavy metals.

This research is considered important because analysis of the situation and environmental conditions are the main factors for plant life which will reveal the factors that make lime plants (Citrus Aurantifolia) commonly found in small-scale gold ore processing areas where levels of heavy metal pollution are high and assess the risk to the population. who consume these plants which have never been discussed in other research.

RESEARCH METHOD

The sample for this research are plants that were taken from the gold ore processing area of Sukamenang Village. The plant samples were gathered by taking parts of the leaves and storing them in a tightly closed and dry sample plastic using a simple sample preservation method. The sample in this study was a lime plant (Citrus Aurantifolia) and sample collection used the proposive method. To ensure sample homogeneity, there are several sample criteria determined by the researcher, namely the same plant age, plant height and plant fertility level. The sample in this study was a lime plant (Citrus Aurantifolia) and sample collection used the proposive method. Sample homogeneity was determined using sample criteria by researchers, namely the same plant age, plant height and plant fertility level. Sukamenang Village is divided into 10 sample stations. At each station, 10 leaves of lime plants (Citrus Aurantifolia) were taken at a minimum distance of 2 meters for each sample which were then composited so that 10 composite samples were obtained at each sample station.

Sample preparation was carried out by grinding the samples that had been collected by using an Ultrasonic cleaner for Fe and Cu samples, and were then filtered using filter paper. Meanwhile, the Hg samples was prepared manually by using a mortar. The preparation process then continued with making standard solutions of Fe, Cu and Hg.

Analysis of the heavy metal content for Copper (Cu), Iron (Fe) and Mercury (Hg) was carried out using the Atomic Absorption Spectrophotometer (AAS) and Mercury Analyzer methods. The heavy metals concentration for Copper (Cu) and Iron (Fe) was determined based on the Kasi/ALH/2016-2017 method, while the concentration of Mercury (Hg) was carried out by using the SNI 06-6992.2-2004 method regarding testing mercury using cold steam using a Mercury Analyzer. The results of the metal concentration data obtained were then calculated to determine the value of Bioconcentration Factor (BCF). Testing for heavy metals in soil and orange plants is needed to determine the bioconcentration value of factors in plants and the EDI value. Heavy metal testing was carried out at the UPT Laboratorium Lingkungan Hidup Sumatra Selatan.

The research data is presented in the form of a frequency distribution data table to see an overview of the concentration values of Copper (Cu), Iron (Fe) and Mercury (Hg) in lime plants (*Citrus aurantifolia*) in small-scale gold ore processing areas. The bioconcentration values of copper (Cu), Iron (Fe) and Mercury (Hg) in lime plants (*Citrus aurantifolia*) in small-scale gold ore processing areas were then analyzed using the following two formula: (USE EPA, 2003).

BCF formula

$$BCF = \frac{Concentration\ of\ heavy\ metals\ in\ plants\ (mg/kg)}{Concentration\ of\ heavy\ metals\ in\ soil\ (mg/kg)}$$

EDI formula (According to Javed & Usmani, 2016)

$$EDI = \frac{(MC\ X\ IR)}{BW\ X\ 10-3}$$

RESULTS AND DISCUSSION

Laboratory analysis provides results of heavy metal concentrations in soil and citrus plants.

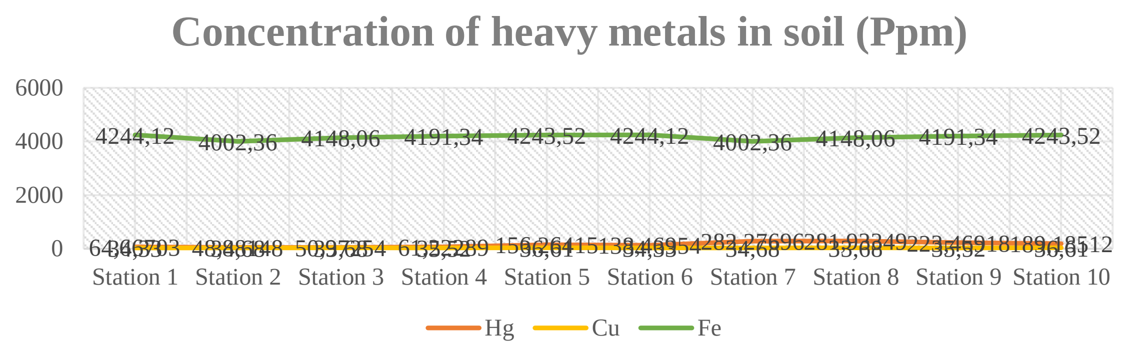

Figure 1. Consentration Of Heavy Metals in Soil

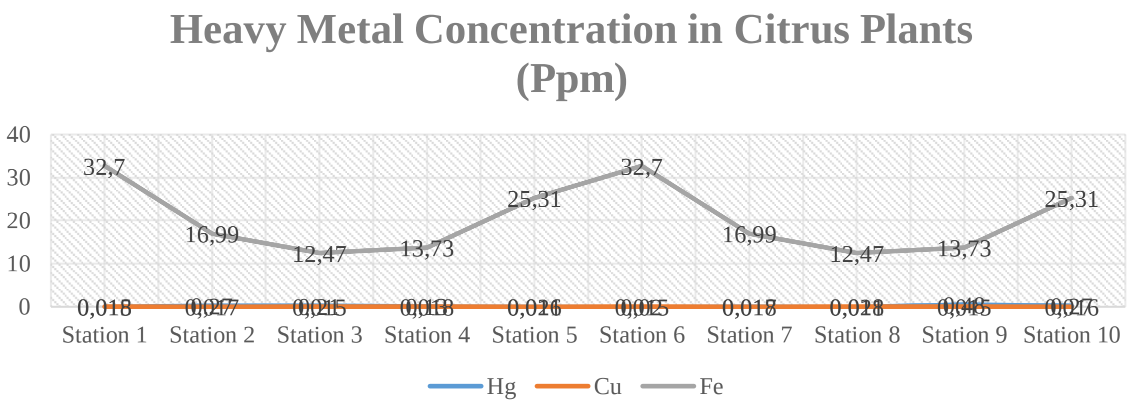

Figure 2. Consentration Of Heavy Metals in Citrus Plants

Concentration of mercury (Hg) has the highest value (0.48) in sample 9 and the lowest (0.018) in sample 1 and 7. Mercury (Hg) also had an average of 0.14 ppm which exceeded the specified threshold value set by SNI 7387 in 2009, which is 0.03 ppm. For Copper (Cu), the highest value is found in sample 4 and 8 at 0.018 and the lowest value is 0.015 in samples 1, 2, 6, and 9. Meanwhile, the average concentration is 0.016 ppm and falls below the specified threshold value set by POM RI 23 in 2017. As for Iron (Fe), it has the highest concentration value of 32.7 in sample 1 and 6 and the lowest value of 12.47 ppm in sample 3 and 8 and has an average value of 20.24 ppm.

The concentration of heavy metals in the soil will affect the concentration of heavy metals in plants growing in that soil (Rc et al. 2015). Heavy metals will bind to soil particles and are stable so they cannot be broken down so they can be absorbed by organisms and plants (R. Chen et al. 2021). Plants can absorb heavy metals from the soil through their roots and vascular systems. In plants themselves, heavy metals can inhibit the plant's ability to produce chlorophyll, increase plant oxidative stress and compromise stomata resistance (Ashraf, Maah, and Yusoff 2011). One of the main routes for heavy metals to enter the human body is by consuming vegetables or fruit contaminated with heavy metals. If you continue to consume these vegetables for a long period of time, heavy metals can accumulate in the body. The first organs that will feel the toxic effects of heavy metals are the kidneys and liver. Furthermore, these heavy metals can damage all body organs (Kacholi 2018)(Adimula et al. 2019).

Once the concentration values of heavy metals in the soil and parts of the plants are known, it can help determine the bioconcentration values of factors through calculations using the formulas. The absorption of chemicals by plant tissues (e.g., roots, stems, leaves) from the environment (e.g., stem, water, air) is usually measured by the bioconcentration factor (BCF). To calculate the BCF, data is needed regarding the heavy metal content in the soil at the research location. The concentration of heavy metals in the soil is quoted from previous research which used the same sample point locations in the same year and at the same time (Torralba et al. 2017) (Burkhard 2021).

The BCF value is calculated by comparing the concentration of heavy metals in plants with the concentration of heavy metals in the soil. BCF is generally determined through laboratory experiments in which plants are grown in contaminated soil (Torralba et al. 2017). Based on the calculation results, the BCF value is found. The results of the calculations of Bioconcentration Factor (BCF) values in lime plants (*Citrus aurantifolia*) for heavy metals iron (Fe), copper (Cu) and mercury (Hg) used the formula (Sanou, Coulibaly, and Coulibaly 2021):

Based on the BFC value, there are 3 categories of plants, there are Acumulator (if the BCF value is >1), Excluder (if the BCF value is <1) and Indicator (BCF value=1) (Baker, 1981). From tables 5, 6, and 7 above, the bioconcentration factor (BCF) values of heavy metals Hg, Cu and Fe in Lime plants (*Citrus aurantifolia*) in small-scale gold ore processing areas at 10 stations are all worth less than 1 (<1). According to Baker (1981), if the BCF value is <1, the plant falls into the excluder category, which are plants that effectively prevent heavy metals from entering the top part of the plant, but the metal concentration around the root area is still high (L. Chen et al. 2018). According to Soemarno (2010), excluder plants are plants that are not sensitive to absorbing and accumulating toxic elements. Ismail et al (2020) explained that excluder is a property where plants limit the absorption of heavy metals in their environment, whether in the sediment or water, but when they enter the plant body, heavy metals will be easily translocated to other parts of the plant body(Wassenaar et al. 2020)(Miller et al. 2019).

Bioconcentration Factor (BCF) of heavy metals is calculated as the quotient of the total of heavy metals in the parts of plants by the total of heavy metal concentration in the soil (Vergara-fl, Bravo, and Díez 2020). The low BCF value is due to the small concentration of heavy metals in parts of the plants and the high concentration of heavy metals in the sediment or in the soil. Another factor that influences lime plants that can still live in an environment contaminated with heavy metals is the type of soil. Based on field observations, the soil in Sukamenang Village is a type of inceptisol soil that is suitable for plantations. The BCF value is used to determine the level of pollution in an environment by measuring the ability of plants to accumulate heavy metals so that if the BCF value is known, a plant's ability to accumulate heavy metals can be determined. According to Takarina and Pin (2017), plants that have a BCF value of more than 1 can be used as bioaccumulators (Takarina and Pin 2019)(Bio Concentration Factor and Translocation Ability of Heavy Metals within Different Habitats of Hydrophytes in Nairobi Dam , Kenya 2014). Previous research also reported that the bioavailability of soil metals to vegetables is influenced by soil properties, soil metal speciation, and plant species. Furthermore, the absorption of heavy metal emissions in the atmosphere through leaves is known to be an important pathway for heavy metal contamination in vegetable plants (D.K. Kulkarni, Azam Sadat Delbari 2014).

Since the BCF value is known for the lime plant (*Citrus aurantifolia*), we can determine the estimated value of heavy metal absorption into the human body by calculating the EDI (Estimated Daily Intake). The EDI value is greatly influenced by several factors, such as the concentration of heavy metals in the organism and the body weight of the respondent (human) (Javed and Usmani 2016). To determine the level of risk on whether the heavy metals are accumulated in an organism's body, it must be determined based on the RfD. For the heavy metal mercury (Hg) the RfD value is 0.0001 mg/kg/day. Meanwhile, the RfD value for Copper is 0.008 and Iron is 0.7 (United States Environmental Protection Agency (USE EPA) 2011). Calculation of the EDI value can be done using the following formula (Ismail 2015):

The RfD value for heavy metal Cu is 4.0 x 10-2 (0.008), RfD for heavy metal Fe is 0.7 and RfD for heavy metal Hg is 0.0001 which have been recommended by the United States Environmental Protection Agency (USE EPA) in 2011. In this study heavy metals such as Fe, Cu and Hg can have a negative impact on health with their respective toxicities.

If this gold ore processing activity without a permit continues, it will continue to cause environmental damage and have a negative impact on the health of the residents. In accordance with the explanation from Rita (2016), if small-scale gold mining activities continue for a long time, it will have a negative impact on environmental and even health. According to Javed & Usmani (2016), the Estimated Daily Intake (EDI) value is greatly influenced by several factors such as the concentration of heavy metals in the organism and the respondent's body weight. The greater the metal concentration in the organism, the greater the EDI value. Conversely, the greater the respondent's weight, the smaller the EDI value. Meanwhile, other factors such as the ingestion rate were made uniform considering that all respondents were adults, with a value of 19.5 × 10-3kg/day (United States Environmental Protection Agency).

Factors that influenced the heavy metal intake make it possible for heavy metals (pollutants) to accumulate in the body. High accumulation of heavy metals in plants can inhibit the plant's ability to produce chlorophyll, increase plant oxidative stress and weaken stomata resistance (Sulaiman and Hamzah 2018) Thus, the presence of heavy metals in plants can be an indicator of the presence of heavy metals in the soil and air around the plants. All plant parts such as large plant leaves, body shells, and fruit can be biomonitors of the presence of heavy metals in the environment around the plant (Aricak et al. 2020). High levels of mercury, Cu and Fe in small-scale gold ore processing areas pose a high risk to plants and humans around the area. This needs to be looked at more deeply because the accumulative properties of heavy metals pose a threat to local communities who consume the plants that grow around them. This is illustrated by the resulting EDI value (Tun 2020)(Iwegbue et al. 2013).

CONCLUSION

The lime plants (*Citrus aurantifolia*) that were planted around the yards of the residents of Sukamenag village fell into the excluder category based on the result of the calculations of Bioconcentration Factor (BCF) values for heavy metals iron (Fe), copper (Cu) and mercury (Hg). This result means that the lime plants are plants that effectively prevent heavy metals from entering the top part of the plant and can survive the polluted areas as a result of the small-scale gold ore processing and mining activities that the residents of the village partaken. However, despite the effectiveness of being an excluder category plant, the heavy metals still have a probability of having a negative impact on the residents' health due to their own toxicities.

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AUTHOR CONTRIBUTIONS

Author 1-2 creates articles and creates instruments and is responsible for research, author 3-4 Analyzes research data that has been collected, author 5-7 assists in research data analysis, instrument validation and input research data.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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