# bioindikator

*by* Ecologi Ecologi

# Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia

Khairun Nisah[1*], Muslem Muslem[1], T. Muhammad Ashari[2], Majral Afkar[1], Muhammad Iqhrammullah[3]

[1] Department of Chemistry, Faculty of Sience and Technology, Universitas Islam Negeri Ar-Raniry, Banda Aceh 23111, Indonesia

[2] Department of Environmental Engineering, Faculty of Sience and Technology, Universitas Islam Negeri Ar-Raniry, Banda Aceh 23111, Indonesia

[3] Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Correspondence: khairun.nisah@ar-raniry.ac.id

| Author | Email |
|---|---|
| Khairun Nisah | khairun.nisah@ar-raniry.ac.id |
| Muslem Muslem | moslem_coolam@yahoo.com |
| T. Muhammad Ashari | T.m.ashari@ar-raniry.ac.id |
| Majral Afkar | afkarmajral@gmail.com |
| Muhammad Iqhrammullah | m.iqhram@oia.unsyiah.ac.id |

**Abstract**

There is a high suspiciousness on mercury contamination associated with the former intense illegal gold mining activities in the watershed of Krueng Cot Satu, Nagan Raya Regency, Provinsi Aceh, Indonesia. The aim of this study is to evaluate the mercury contamination residue in the water, soil, and vegetable fern (*Pityrogramma calometanos* (L) Link) samples collected from locations in the already closed artisanal gold mining sites. The sampling locations were purposively determined by considering their closeness to the previous gold mining activities sites. The content of mercury was analyzed using flow injection for atomic spectroscopy – atomic absorption spectroscopy. The method used were validated by linearity, Limit of Detection (LoD), Limit of Quantification (LoQ), Relative Standard Deviation (RSD), and recovery. The validation test showed that this method is well linear, sensitive, accurate, and precise with a correlation coefficient, LoD, LoQ, RSD and recovery of 0.9999, 0,0477 $\mu$g/L, 0,1447 $\mu$g/L, 2,96 % and 95-105 %, respectively. Herein, we found that the concentrations of mercury contents in the water samples were below the detectable range. However, we found a high range of mercury concentration of 0.236 – 0.328 $\mu$g/g in soil, with the highest concentration obtained in sample collected from the riverbank. Fern sample collected near the riverbank contained mercury in all over its part and concentrated in the root (0.408 $\mu$g/g in the leaves, 0.276 $\mu$g/g – stalks, and 9.994 $\mu$g/g – roots). Meanwhile, the absence of mercury contamination was obtained in the leaves and stalks of fern samples collected far from the riverbank. The roots, however, were detected with mercury contamination with the highest concentration reaching 27.660 $\mu$g/g. Despite its disappearance in the water, mercury contamination residue from the former artisanal gold mining activities still could be traced in the soil and heavy metal accumulating plant – *P. calometanos* (L) Link.

**Keywords**: Aceh, Artisanal gold mining, mercury, ferns, *Pityrogramma calometanos*

## 1. Introduction

The presence of heavy metal in environment is yet still a common problem to this date. The heavy metal could be originated from natural activities such as volcano [Mandon, C.L., et.al, 2019], hot spring manifestations [Idroes, R,et.al. 2019a], erosion [Fang, H., et al, 2016], geyser [Ciesielczuk, J., 2013], and fumarole [Idroes, R.,et.al, 2019]. Moreover, anthropogenic activities also contribute to the heavy metal pollution including industries [Hoang et al., 2021], mining [Wahidah, S., 2019], or agriculture [Seiler, C. and Berendonk, 2012]. Dynamic environmental system causes the widespread of heavy metal pollution from one ecosystem to another. Heavy metals present in the soil could be transferred to plants, animals, and human. Heavy metal could give detrimental effect against human health due to its ability of interacting and accumulated in human body via protein [E. Suhartono, 2018], blood, tissues [Fazio, 2014] or even bones [*E. Suhartono,* 2019]. Furthermore, heavy metal contamination could be transported by water and contaminate aquatic ecosystem including the sediment and aquatic organisms [Liu, 2014].

Illegal gold mining in Indonesia, as reported by others, has caused a mercuy pollution [Rozo, 2020], and followed by the degradation of environmental quality [Spiegel et al., 2018]. Due to its sensitive nature, the illegal gold mining and processing have become a primary source of severe heavy metal pollution that is significant and controllable. Gold is separated from its ore using mercury [Torkaman et al., 2021]. Usually the processing site is located near the watershed [González-Valoys et al., 2022]. It is ascribed to the fact that the processing requires a lot of water, and in addition, its location near the watershed would ease the waste discharge [Saniewska et al., 2022]. The waste effluent is discharged directly to the river, meanwhile the solid waste is stacked around the site without proper management. Aceh is a Province with many illegal gold mining practices, of which is located in Nagan Raya Regency [Zulkarnaini, 2019]. Based on our observation on the site, the gold processing sites tend to be located near the community residence. At the moment, the illegal gold mining and processing sites have been identified and closed by the government, but its heavy metal residue still impacts the surrounding environments [Neto & Soares, 2021].

Land reclamation of the heavy metal contaminated location is required to be carried out to recover the ecosystem, especially those nearby the community living area and watershed area [Niu et al., 2021]. It is owing to the fact that human activities and river flows could increase the spread of the heavy metal contamination. One of land reclamation approaches is by utilizing plant-based biosorbents [Li et al., 2015; Zhao et al., 2018; Makarova et al., 2022]. Nonetheless, the method tend to face challenges in determining the type of suitable plant for the specific climate and geographical condition of the intended reclamation sites (Narayanasamy, Sundaram, Sundaram, & Vo, 2022). Indeed, there are other alternative of using biobased adsorbent, but it could not be an option due to its high-price production (Rahmi, Julinawati, Nina, Fathana, & Iqhrammullah, 2022; Rahmi, Lelifajri, et al., 2022).

Among many biosorbent plants, the one that is massively abundant in the watershed is vegetable fern. This devision plant is commonly found in the wild with humid condition, such as river banks [Nagalingum et al., 2008]. A previous report suggested that the devision plant of Pteridophyta could absorb excessive contaminants, either organic or inorganic Alizadeh et al., 2022. In Aceh itself, ferns could be found thriving along the watershed. The plant is commonly used by the village communities as vegetable. Vegetable ferns has become one of local delicacies, known as *paku teu peuleumak* (translated as coconut milk-based soup of vegetable ferns). Therefore, it is crucial to perform the analysis of mercury content in the vegetable ferns growing in the area of former illegal gold mining. Other than investigating its potential as mercury biosorbent, the analysis is required to map the mercury pollution on the plant (leaves, stems, and roots) which is useful when processing the vegetable as food ingredient.

## 2. METHODS

### 2.1 Materials

Chemicals used in this research were Argon gas, $HNO_3$, HCl, and $Hg(NO_3)_2$ – for standard solution. All chemicals were analytical grade and procured from Merck (Selangor, Malaysia). Water, soil, and vegetable ferns sample were collected from locations described in the following sections.

### 2.2 Sampling Techniques

The sampling locations of this research were former illegal gold mining and processing sites located near the watershed of Krueng Cot Satu in Panton Bayam Sub-District, Nagan Raya Regency, Aceh Province, Indonesia. The sampling was carried out on 21 march 202

#### *2.2.1 Determination of Sampling Points*

Three sampling points for soil and fern samples were determined purposively in three different locations which were formerly used as gold mining and processing sites, labelled as point I, II, and III. The distribution of the locations was presented in a map (Figure 1). Sampling point 3 were located in the reiverbank of Krueng Cot Satu, where we assumed as a final point of the mercury-contaminated wastewater flew before entering the river. Three sampling points were also determined purposively in the river flowing through the former illegal gold mining.

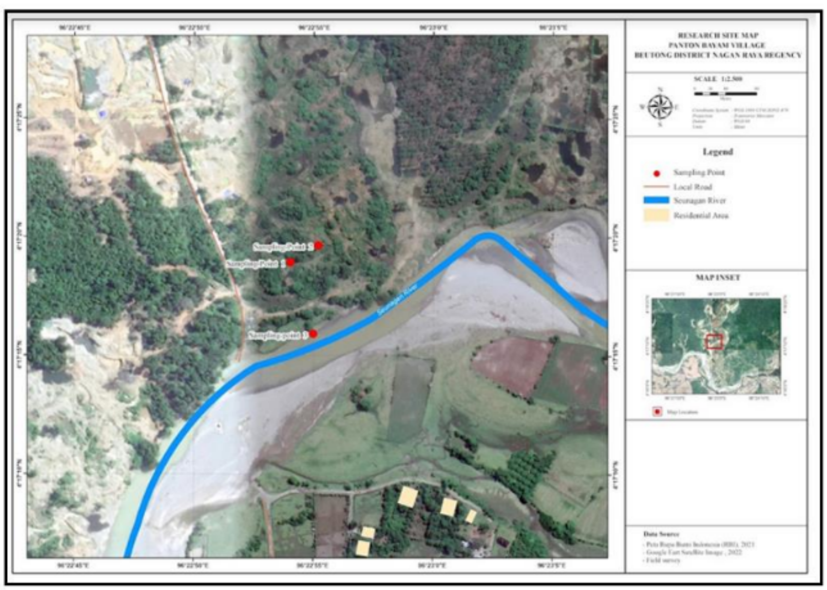

**Figure 1**. Sampling point of soil and fern plant in former illegal gold mining in Krueng Cot Satu, in Panton Bayam Sub-District, Nagan Raya Regency, Aceh Province, Indonesia.

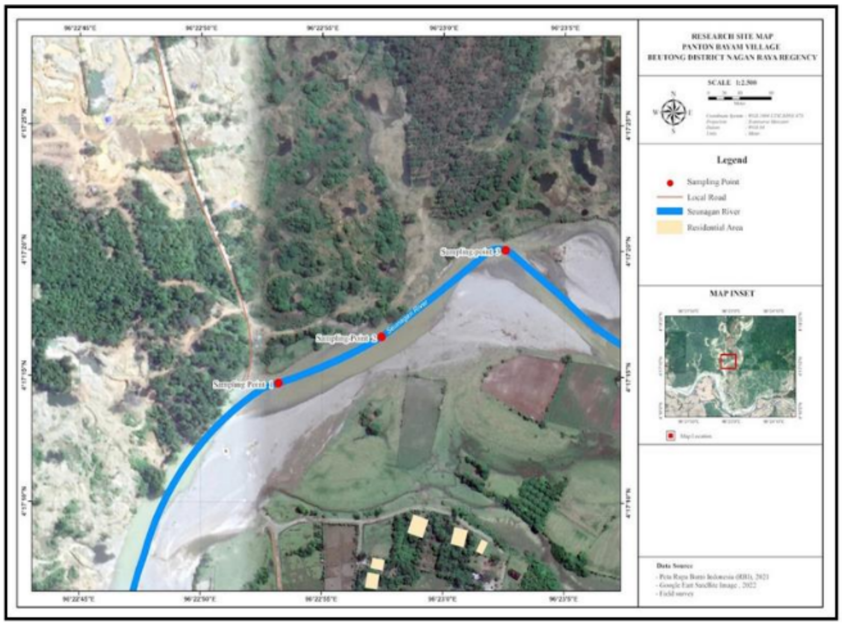


**Figure 2**. Sampling point of soil and fern plant in former illegal gold mining in Krueng Cot Satu, in Panton Bayam Sub-District, Nagan Raya Regency, Aceh Province, Indonesia.

### *2.2.2 Soil Sample Collection*

Sediment samples were collected using stainless steel scoop in the predetermined locations of former gold mining and processing. Samples were stored in a plastic container, labeled according to the locations (for example SS-01 for soil sample from sampling point 1), and transported to the laboratory.

### *2.2.3 Fern Sample Collection*

Several ferns grew in the three predetermined sampling points (1, 2, and 3) were randomly chosen and pulled out using stainless steel scoop from the soil. The samples were collected without considering the age criteria. The plants were placed in a polyethylene bag with soil before transported to the laboratory. Taxonomic examination was carried out in the Laboratory of Biology, Universitas Syiah Kuala according to the published guideline [Sundra, 2016]. It is then known that the species of the plant was *Pityrogramma calometanos* (L) Link with its detailed taxonomic identities presented in Table 1.

**Tabel 1**. Taxonomic identity of the collected fern

| **Taxonomic ranks** | **Name** |
|---|---|
| Kingdom | Plantae |
| Sub kingdom | Tracheobionta |
| Division | Pteridophyta |

| | |
|---|---|
| Class | Filicopsida |
| Sub class | Polypoditae |
| Order | Polypodiaes |
| Family | Pteridaceae |
| Genus | *Pityrogramma Link* |
| Species | *Pityrogramma calometanos* (L) Link |

### *2.2.4 Water Sample Collection*

The water samples were collected using plastic scoop and stored in a polyethylene bottle, which was priorly washed with $HNO_3$ (once) and the water sample (three times). All samples were preserved by reducing its pH level to pH<2 with $HNO_3$ and stored in a refrigerator at 4°C ± 2°C [SNI, 2021]. Each of the water samples was labeled according to the sampling point (for example WS-01 for water sample collected from sampling point 1). All samples were transported to the laboratory for mercury content determination using flow injection for atomic spectroscopy – atomic absorption spectroscopy (FIAS-AAS).

## 2.3 Sample Preparation

### *2.3.1 Soil Sample Preparation*

Plastic debris and leaves were separated from the soil sample, and then air-dried at room temperature. Dried sample was crushed homogenously and sieved (100 mesh). Sample was weighed 3 g and inserted into a Vassel, added with 25 mL distilled water, and rigorously shaken. Into the mixture, 10 mL $HNO_3$ and 5 mL HCl were added. Vassel container were sealed and adjusted with a Vassel spanner before inserted into a digestion microwave, run for 15 minutes. The obtained liquid was filtered and dissolved in distilled water up to 100 mL.

### *2.3.2 Fern Sample Preparation*

Each fern sample were cut according to its parts (leaves, stalks, and roots). Afterward, the size of each part was reduced using a stainless-steel knife. The sample was air-dried at room temperature before crushed until homogenous. As much as 3 g sample powder was inserted into Vassel container, added with 25 mL distilled water, and rigorously shaken. 15 mL solution of $HNO_3$:HCl (2:1) was added into the sample mixture, sealed, and adjusted in the Vassel spanner in a Microwave Digestion System (run for 15 minutes). The liquid produced thereafter was filtered and dissolved in distilled water until the volume reached 100 mL.

### *2.3.3 Mercury Analysis using FIAS-AAS*

A sample in liquid form was injected into FIAS through autosampler. The determination of mercury content was performed at wavelength of 253.7 nm. Each sample was determined in triplicate [EPA, 2021].

### *2.3.4 Method Validation*

The parameters used for validation were linearity, precision, LoD, LoQ and recovery. The linearity is calculated by linear regression between the concentration and absorbance from five standard solution series. Precision is determined by standard deviation from three repition measurement of standard solution. LoD and LoQ are calculated by the acquisition of regression parameter from the calibration curve regression line. Recovery is determined measuring known concentration of standard solution.

## 3. Results and Discussion

### 3.1 Method Validation

#### *3.1.1 Linearity, Limit of Detection and Limit of Quantification*

The standard solutions of Hg $(NO_3)_2$ were analyzed in concentration range of 0 - 50 $\mu$g/L. The absorbances obtained were plotted in linear regression using LINEST to obtain regression parameters (Table 2). The method used is well linear where the coefficient of determination obtained was 0.9999. Based on the the standard deviaton of regression, the method used is well sensitive where the LoD and LoQ calculated were 0,0477 $\mu$g/L and 0,1447 $\mu$g/L, respectively.

**Table 2**. Linearity and uncertainty of calibration curve threshold

| Parameters | Value |
|---|---|
| Slope | 0,006197143 |
| Intercept | 0,000432143 |
| Standar deviation of slope | 0,000002395 |
| Standard deviation of intercept | 0,000065600 |
| Coefficient of determination | 0,999999701 |
| Standard deviation of regression | 0,000089600 |

#### *3.1.2 Precision and Recovery*

The precision of method used was identified by testing of 10 $\mu$g/L standard solution in three reapetation. The result showed that the method was well precise with % RSD of 2,96 % (Table 3). The accuracy of the method was determined by calculating the concentration of 10, 20 and 50 $\mu$g/L standard solution. The result showed that the method is high accurate with the recovery in range of 95-105 % (Table 3).

**Table 3**. Recovery and relative standard deviation test

| Recovery | | % RSD |
|---|---|---|
| Standard solution test | % Recovery | |
| 10 | 99,76 | 2,96 |
| 20 | 100,08 | |
| 50 | 96,78 | |

### 3.2 Mercury Content in Water

Identification of mercury content in the river water of Kreung Cot Satu was performed to detect the source of pollution which possible affect the mercury content within the former gold mining area. The area was located at the riverbank which could have a contact with the water river when the water debit increases due to natural factors such as rain or flood. Initially we speculate the mercury migh present in the river water attributed to many former gold mining sites surrounding the river, as reported by several studies [Aminah, A., Hasan, E. and Ubaidullah, 2021; Barron, 2019; Meilina, H. and Ramli, 2021]. Moreover, the illegal gold processing is commonly known for its action of discharging the wastewater to the river [Basri, H. and Prayudi, 2022]. Nonetheless, in this present study, the presence of mercury was not detected in all sampling points (Table 4). The absence of mercury could be influenced by geographical factor, phase concentraiton [Cui et al., 2021], salinity [Bełdowska et al., 2015], and the mixing of river and sea waters [Saniewska et al., 2022]. There is a possibility that the mercury has been carried to the ocean, as suggested by a previous research [Saniewska et al., 2022]. Hence, the mercury content left in the water sample is too small to be detected.

**Tabel 4.** Content of mercury in water from Krueng Cot Satu River which shares the same location with former gold mining site

| Coordinate | Water Sample | |
|---|---|---|
| | **Label** | **[Hg] (μg/L)** |
| 96° 22' 53,439"E<br>4° 17' 14,731"N | WS-01 | Not detected |
| 96° 22' 57,684" E<br>4° 17' 16,582" N | WS-02 | Not detected |
| 96° 23' 2,791" E<br>4° 17' 20,03E | WS-03 | Not detected |

**Tabel 5.** Content of mercury in soil samples collected from Krueng Cot Satu River which shares the same location with former gold mining site

| Coordinate | Soil Sample | |
|---|---|---|
| | **Label** | **[Hg] (μg/g)** |
| 4°17'19.04"N<br>96°22'55.46"E | SS-01 | 0.271 |
| 4°17'19.42"N<br>96°22'56.46"E | SS-02 | 0.236 |
| 4°17'17.48"U<br>96°22'57.03"E | SS-03 | 0.328 |

### 3.3 Mercury Content in Soil

The presence of mercury and its content level in soil samples have been presented in Table . The results revealed that all samples from the three sampling locations contained mercury ranged between 0.236 and 0.328 $\mu$g/g. The highest mercury concentration (0.328 $\mu$g/g), was observed in sampling point 3, which was the location where the mercury entered the river. These data suggest that the mercury was carried from the land to the river by means of rain or erosion. The presence of mercury in the soil sample, and not in the water sample, indicate that the mercury was retained in the soil and possible distributed to somewhere else in the water. In a study, mercury could be reserved in the soil even for years [Zhou et al., 2015].

Mercury containing soil is an indicator of food chain contamination, which attracting global attention [Fernandes et al., 2021]. The presence of mercury has been attributed to the antrophogenic activity, especially gold mining [Yoshimura et al., 2021]. Not only mercury, heavy metals such as Cd, Cu, and Pb were found increased in area affected by artisanal gold mining (Nasir et al., 2021). People living near the contaminated locations could be exposed to mercury via wild vegetables grown therein. Of which is vegetable fern which has been considered as local delicacies.

### 3.4 Mercury Content in Vegetable Ferns

The contents of mercury in vegetable ferns (*P. calometanos* (L) Link) collected in this present study have been presented in Table 5. Leaves and stalks of the ferns collected from sampling points 1 and 2 were not detected for the presence of mercury. Meanwhile, the sample from point 3 (riverbank) had mercury in all over its part. On contrary, the root parts of the ferns from all sample points (1, 2, and 3) were contaminated with mercury with concentrations ranging from 4.824 to 27.660 $\mu$g/L. As can be seen, the presence of mercury in stalks and leaves is not correlated with the concentration of mercury in the root. However, the distribution of mercury in the parts of a fern could be associated with the mercury level in the soil, where soil sample from point 3 had the highest concentration as compared with others. Therefore, it is not safe to consume ferns grow in the riverbank of Kreung Cot Satu. The representation image of mercury absorption by the fern collected from the riverbank area (point 3) and the area far from the riverbank (point 1 and 2) has been presented in Figure 1.

**Tabel 6.** Mercury content in fern plant growing in former illegal gold mining

| **Sample** / **Location** / **Coordinates** | **[Hg] ($\mu$g/g)** | | |
|---|---|---|---|
| **Location** | **1** | **2** | **3** |
| **Coordinates** | 4°17'19.04"N 96°22'55.46"E | 4°17'19.42"N 96°22'56.46"E | 4°17'17.48"U 96°22'57.03"E |
| Leaves | Not detected | Not detected | 0.408 |
| Stalks | Not detected | Not detected | 0.276 |
| Roots | 4.824 | 27.660 | 9.994 |

Moreimportantly, we noted that the smallest mercury concentration (4.824 $\mu$g/L) in the fern roots was more than 17 times higher than the concentration in the soil sample. Hence, we stipulate that the mercury was absorbed and accumulated in the root of fern, proving its ability as biosorbent for mercury. Not only as biosorbent, the enrichment of heavy metal in a solid sample such as the root is beneficial for contamination monitoring techniques using laser spectroscopy (Iqhrammullah et al., 2021; Nisah et al., 2022). As suggested previously, plants act as direct receivers of heavy metal contaminant through water absorption [Pal & Sukul, 2022]. Based on the aforementioned study [Pal & Sukul, 2022], ferns absorbs heavy metal along with the ability to accumulate and tolerate the heavy metal.

It is worthnoting that *P. calometanos* is widely distributed in tropical region [Lianah, L., at.al,2021], and usually grows near the ground water surface [Luthardt et al., 2021]. The plant itself has been used as integrative medicine for dysentery [Koniyo, Y.,at.al, 2019]. In addition, it has also been used by the locals to reduce the concentration of arsenic in the water [Koniyo, Y.,at.al, 2019]. The use of this plant for consumption should be taken carefully, by considering the level of heavy metal contamination in the place where the plants grow.

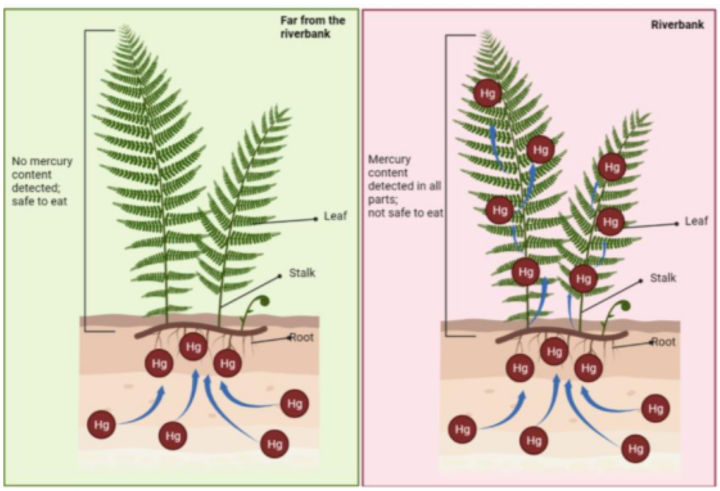


**Figure 3.** Representation of vegetable ferns absorbing Hg from the contaminated soil. In samples collected from sampling points far from the riverbank (point 1 and 2), the mercury was only detected in its root, while the mercury was not detected in either the stalks or leaves. Hence, the stalks and leaves of a vegetable fern grow far from the riverbank is safe to eat. All parts of vegetable ferns collected from in the riverbank (point 3) contained mercury, hence is not safe to eat.

## 4. Conclusions

The residues of mercury from the former illegal gold mining and processing are still threatening the people living in Panton Bayam Sub-District, Nagan Raya Regency, Aceh Province, Indonesia. The determination of mercury content in this research was performed by validated method. The validation test showed that this method is well linear, sensitive, accurate, and precise with a correlation coefficient, LoD, LoQ, RSD and recovery of 0.9999, 0,0477 $\mu$g/L, 0,1447 $\mu$g/L, 2,96 % and 95-105 %, respectively. Though the mercury is not found in water samples, its presence is still detected in high concentration range (0.236 – 0.328 $\mu$g/g) in soil samples. The presence of mercury in soil could contaminate the wildly grown vegetables consumed by the locals, of which is vegetable ferns (*P. calometanos* (L) Link). For vegetable ferns grow far from the riverbank, it is safe to consume their stalks and leaves but not the roots. However, for those grow in the riverbank area, ones should caucious on the Hg contamination in the leaves and stalks. Hence, we recommend the ban of fern consumption if it grows in the riverbank contaminated by high concentration of Hg. More investigations need carried out to fully understand the pattern of Hg distribution in the plant grown in contaminated soil in order to make more comprehensive regulation.

## 5. Acknowledgement

The authors appreciate the funding given by *Lembaga Penelitian dan Pengabdian Kepada Masyarakat* [LPPM] Universitas Islam Negeri Ar-Raniry through *Dana Penelitian Internal* scheme with contract no.: 4533/PPK-UIN/PUSLIT/I/2020.

## 6. References

1.Alizadeh, S., Abdollahy, M., Khodadadi Darban, A., & Mohseni, M. (2022). Theoretical and experimental comparison of rare earths extraction by [P6,6,6,1,4][Decanoate] bifunctional ionic liquid and D2EHPA acidic extractant. *Minerals Engineering*, *180*(March), 107473. https://doi.org/10.1016/j.mineng.2022.107473

2.Aminah, A., Hasan, E. and Ubaidullah, U. (2021). Impelementation of Regulations of Aceh Jaya Regent Number 21 Year 2011 Regarding the Management of Artisanal Gold Mining. *Jurnal Public Policy*, *7(1)*, 17-20.

3.Barron, P. (2019). *Small Episodic Violence in Postconflict Aceh. In When Violence Works . Cornell University Press.* (Vol. 6).

4.Basri, H. and Prayudi, H. C. (2022). Analysis of water pollution index around gold mining in the downstream of Krueng Kluet sub-watershed. In *IOP Conference Series: Earth and Environmental Science*. (p. 012050).

5.Bełdowska, M., Jędruch, A., Słupkowska, J., Saniewska, D., & Saniewski, M. (2015). Macrophyta as a vector of contemporary and historical mercury from the marine environment to the trophic web. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-014-4003-4

6.Ciesielczuk, J., Żaba, J., Bzowska, G., Gaidzik, K. and Głogowska, M. (2013). Sulphate efflorescences at the geyser near Pinchollo, southern Peru. *Journal of South American Earth Sciences*, *42*., 186-193.

7.Cui, X., Lamborg, C. H., Hammerschmidt, C. R., Xiang, Y., & Lam, P. J. (2021). The Effect of Particle

Composition and Concentration on the Partitioning Coefficient for Mercury in Three Ocean Basins. *Frontiers in Environmental Chemistry*, *2*(May), 1–16. https://doi.org/10.3389/fenvc.2021.660267

8.E. Suhartono, I. Thalib, I. Aflanie, Z. Noor, and R. Idroes, “. (2018). Study of Interaction between Cadmium and Bovine Serum Albumin with UV-Vis Spectrocopy Approach. In *IOP Conference Series: Materials Science and Engineering* (Vol. 350, p. 12008).

9.E. Suhartono, Z. Noor, Edyson, W. Y. Budianto, and R. Idroes, “Effect of chronic lead exposure on bone using ATR-FTIR spectroscopy,” in AIP Conference Proceedings,. (2019), *2108*(1), 20025.

10.EPA. (2021). *EPA ' s 2021 Report on the Environment : Science Report*.

11.Fang, H., Huang, L., Wang, J., He, G. and Reible, D. . (2016). Environmental assessment of heavy metal transport and transformation in the Hangzhou Bay, China. *Journal of Hazardous Materials*., *302*, pp.447-457.

12.Fazio, F., Piccione, G., Tribulato, K., Ferrantelli, V., Giangrosso, G., Arfuso, F. and Faggio, C. (2014). Bioaccumulation of heavy metals in blood and tissue of striped mullet in two Italian lakes. *Journal of Aquatic Animal Health*, *(26)4*, 278-284.

13.Fernandes, I. O., Gomes, L. F., Monteiro, L. C., Dórea, J. G., & Bernardi, J. V. E. (2021). A Scientometric Analysis of Research on World Mercury (Hg) in Soil (1991–2020). *Water, Air, and Soil Pollution*, *232*(7). https://doi.org/10.1007/s11270-021-05222-z

14.González-Valoys, A. C., Arrocha, J., Monteza-Destro, T., Vargas-Lombardo, M., Esbrí, J. M., Garcia-Ordiales, E., Higueras, P. (2022). Environmental challenges related to cyanidation in Central American gold mining; the Remance mine (Panama). *Journal of Environmental Management*, *302*. https://doi.org/10.1016/j.jenvman.2021.113979

15.Hoang, H. G., Chiang, C. F., Lin, C., Wu, C. Y., Lee, C. W., Cheruiyot, N. K., Bui, X. T. (2021). Human health risk simulation and assessment of heavy metal contamination in a river affected by industrial activities. *Environmental Pollution*, *285*(May), 117414. https://doi.org/10.1016/j.envpol.2021.117414

16.Idroes, R, Yusuf, M., Alatas, M., Subhan, Lala, A., Muslem, Riza, M. (2019). Geochemistry of warm springs in the Ie Brôuk hydrothermal areas at Aceh Besar district. *IOP Conference Series: Materials Science and Engineering*, *523*, 012010. https://doi.org/10.1088/1757-899X/523/1/012010

17.Idroes, Rinaldi, Yusuf, M., Saiful, S., Alatas, M., Subhan, S., Lala, A., Mahlia, T. M. I. (2019). Geochemistry Exploration and Geothermometry Application in the North Zone of Seulawah Agam, Aceh Besar District, Indonesia. *Energies*, *12*(23), 4442. https://doi.org/10.3390/en12234442

18. Iqhrammullah, M., Suyanto, H., Rahmi, Pardede, M., Karnadi, I., Kurniawan, K. H., Abdulmadjid, S. N. (2021). Cellulose acetate-polyurethane film adsorbent with analyte enrichment for in-situ detection and analysis of aqueous Pb using Laser-Induced Breakdown Spectroscopy (LIBS). *Environmental Nanotechnology, Monitoring & Management*, *16*, 100516. https://doi.org/https://doi.org/10.1016/j.enmm.2021.100516

19.Koniyo, Y., Lumenta, C., Olii, A.H. and Mantiri, R. O. (2019). The characteristic and nutrients concentrated leaves of vegetable fern (Diplazium esculentum (Retz.) Swartz) live in dofferent locations. In *Journal of Physics: Conference Series* (Vol. 1387, No., p. 012003).

20.Li, J., Yu, H., & Luan, Y. (2015). Meta-analysis of the copper, zinc, and cadmium absorption capacities of aquatic plants in heavy metal-pollutedwater. *International Journal of Environmental Research and Public Health*, *12*(12), 14958–14973. https://doi.org/10.3390/ijerph121214959

21. Lianah, L., Kusumarini, N., Rochmah, F., Orsida, F., Mukhlisi, M., Ahmad, M.U. and Nadhifah, A. (2021). Bryophyte Diversity in Mount Prau, Blumah Village, Central Java. *Jurnal Biodjati*, *6(1)*, 23-35.

22. Liu, J., Wu, H., Feng, J., Li, Z. and Lin, G. (2014). Heavy metal contamination and ecological risk assessments in the sediments and zoobenthos of selected mangrove ecosystems, South China. *Catena.*, *119*, 136-142.

23. Luthardt, L., Galtier, J., Meyer-Berthaud, B., Mencl, V., & Rößler, R. (2021). Medullosan seed ferns of seasonally-dry habitats: old and new perspectives on enigmatic elements of Late Pennsylvanian–early Permian intramontane basinal vegetation. *Review of Palaeobotany and Palynology*, *288*. https://doi.org/10.1016/j.revpalbo.2021.104400

24. Makarova, A., Nikulina, E., Tsirulnikova, N., Pishchaeva, K., & Fedoseev, A. (2022). Effect of monoethanolamine salt-containing dicarboxylic acid and plant growth regulators on the absorption and accumulation of mercury. *Saudi Journal of Biological Sciences*, (xxxx). https://doi.org/10.1016/j.sjbs.2022.02.035

25. Mandon, C.L., Christenson, B.W., Schipper, C.I., Seward, T.M. and Garaebiti, E. (2019). Metal transport in volcanic plumes: A case study at White Island and Yasur volcanoes. *Journal of Volcanology and Geothermal Research, 369*, 155-171.

26. Meilina, H. and Ramli, I. (2021). Water quality index and the sediment criteria due to anthropogenic activity in West Aceh District, Indonesia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 922, p. 012042).

27. Nagalingum, N. S., Nowak, M. D., & Pryer, K. M. (2008). Assessing phylogenetic relationships in extant heterosporous ferns (Salviniales), with a focus on Pilularia and Salvinia. *Botanical Journal of the Linnean Society*, *157*(4), 673–685. https://doi.org/10.1111/j.1095-8339.2008.00806.x

28. Narayanasamy, S., Sundaram, V., Sundaram, T., & Vo, D.-V. N. (2022). Biosorptive ascendency of plant based biosorbents in removing hexavalent chromium from aqueous solutions – Insights into isotherm and kinetic studies. *Environmental Research*, *210*(January), 112902. https://doi.org/10.1016/j.envres.2022.112902

29. Nasir, M., Muchlisin, Z., Saiful, S., Suhendrayatna, S., Munira, M., & Iqhrammullah, M. (2021). Heavy Metals in the Water, Sediment, and Fish Harvested from the Krueng Sabee River Aceh Province, Indonesia. *Journal of Ecological Engineering*, *22*(9), 224–231. https://doi.org/10.12911/22998993/141643

30. Neto, I. F. F., & Soares, H. M. V. M. (2021). Simple and near-zero-waste processing for recycling gold at a high purity level from waste printed circuit boards. *Waste Management*, *135*(April), 90–97. https://doi.org/10.1016/j.wasman.2021.08.025

31. Nisah, K., Rahmi, Ramli, M., Iqhrammullah, M., Mitaphonna, R., Hartadi, B. S., Safitri, E. (2022). Controlling the diffusion of micro-volume Pb solution on hydrophobic polyurethane membrane for quantitative analysis using laser-induced breakdown spectroscopy (LIBS). *Arabian Journal of Chemistry*, *15*(6), 103812. https://doi.org/10.1016/j.arabjc.2022.103812

32. Niu, L., Li, J., Luo, X., Fu, T., Chen, O., & Yang, Q. (2021). Identification of heavy metal pollution in

estuarine sediments under long-term reclamation: Ecological toxicity, sources and implications for estuary management. *Environmental Pollution*, *290*(July), 118126. https://doi.org/10.1016/j.envpol.2021.118126

33. Pal, N., & Sukul, S. (2022). Consequences of copper and lead stress on biochemical properties and mitotic chromosomal behavior of two thelypteroid ferns and their potential in tolerance of those metals. *South African Journal of Botany*, *147*, 53–62. https://doi.org/10.1016/j.sajb.2021.12.028

34. Rahmi, Julinawati, Nina, M., Fathana, H., & Iqhrammullah, M. (2022). Preparation and characterization of new magnetic chitosan-glycine-PEGDE (Fe3O4/Ch-G-P) beads for aqueous Cd(II) removal. *Journal of Water Process Engineering*, *45*, 102493. https://doi.org/10.1016/j.jwpe.2021.102493

35. Rahmi, R., Lelifajri, L., Iqbal, M., Fathurrahmi, F., Jalaluddin, J., Sembiring, R., Iqhrammullah, M. (2022). Preparation, Characterization and Adsorption Study of PEDGE-Cross-linked Magnetic Chitosan (PEDGE-MCh) Microspheres for Cd2+ Removal. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-022-06786-6

36. Rozo, S. V. (2020). Unintended effects of illegal economic activities: Illegal gold mining and malaria. *World Development*, *136*, 105119. https://doi.org/10.1016/j.worlddev.2020.105119

37. Saniewska, D., Bełdowska, M., Szymczak, E., Kuliński, K., Bełdowski, J., Voss, M., Burska, D. (2022). Processes affecting the transformation of mercury in the coastal zone in the vicinity of two river mouths in the southern Baltic Sea. *Marine Chemistry*, *238*(November 2021). https://doi.org/10.1016/j.marchem.2021.104065

38. Seiler, C. and Berendonk, T. U. (2012). Heavy metal driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture. *Frontiers in Microbiology*., (3), 399.

39. SNI. (2021). AWater and wastewater - Part 57: Methods of water surface sampling collection. *Sni 8995:2021*, *59*, 19.

40. Spiegel, S. J., Agrawal, S., Mikha, D., Vitamerry, K., Le Billon, P., Veiga, M., Paul, B. (2018). Phasing Out Mercury Ecological Economics and Indonesia's Small-Scale Gold Mining Sector. *Ecological Economics*, *144*(July 2017), 1–11. https://doi.org/10.1016/j.ecolecon.2017.07.025

41. Sundra, I. K. (2016). *Analytical methods and technique for land flora and fauna*. Denpasar, Bali.: Universitas Udayana.

42. Torkaman, P., Veiga, M. M., de Andrade Lima, L. R. P., Oliveira, L. A., Motta, J. S., Jesus, J. L., & Lavkulich, L. M. (2021). Leaching gold with cassava: An option to eliminate mercury use in artisanal gold mining. *Journal of Cleaner Production*, *311*, 127531. https://doi.org/10.1016/j.jclepro.2021.127531

43. Wahidah, S., Khairi, Lelifajri, Idroes, R., Rahmadi, Lala, A., Mahmudi, Muslem, and Japnur, A. F. (2019). Analysis of mercury and its distribution patterns in water and sediment samples from Krueng Sabee, Panga and Teunom rivers in Aceh Jaya. In *IOP Publishing*. (p. 012016.).

44. Yoshimura, A., Suemasu, K., & Veiga, M. M. (2021). Estimation of Mercury Losses and Gold Production by Artisanal and Small-Scale Gold Mining (ASGM). *Journal of Sustainable Metallurgy*, *7*(3), 1045–1059. https://doi.org/10.1007/s40831-021-00394-8

45. Zhao, L., Wang, J., Zhang, P., Gu, Q., & Gao, C. (2018). *Absorption of heavy metal ions by alginate*.

*Bioactive Seaweeds for Food Applications: Natural Ingredients for Healthy Diets*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-813312-5.00013-3

46. Zhou, J., Wang, Z., Zhang, X., & Chen, J. (2015). Distribution and elevated soil pools of mercury in an acidic subtropical forest of southwestern China. *Environmental Pollution*, *202*(November 2014), 187–195. https://doi.org/10.1016/j.envpol.2015.03.021

47. Zulkarnaini. (2019). Gold mining in Aceh.

bioindikator

ORIGINALITY REPORT

| 5% | 3% | 2% | 0% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

| | | |
|---|---|---|
| 1 | www.mdpi.com<br>Internet Source | 3% |
| 2 | Rahmi Rahmi, Lelifajri Lelifajri, Mudassar Iqbal, Fathurrahmi Fathurrahmi et al. "Preparation, Characterization and Adsorption Study of PEDGE-Cross-linked Magnetic Chitosan (PEDGE-MCh) Microspheres for Cd2+ Removal", Arabian Journal for Science and Engineering, 2022<br>Publication | 1% |
| 3 | I Subandar, L Hakim, I Suliansyah, S Syakur. "Identification of antagonistic bacteria against peanut stem rot disease (Sclerotium rolfsii Sacc.) on the peatland of Kuala Pesisir-Nagan Raya, Indonesia", IOP Conference Series: Earth and Environmental Science, 2021<br>Publication | 1% |
| 4 | www.science.gov<br>Internet Source | 1% |

| | | | |
|---|---|---|---|
| Exclude quotes | On | Exclude matches | < 25 words |
| Exclude bibliography | On | | |