AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

Editorial System registration to Journal of Ecological Engineering

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 20 Mei 2022 08.32
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

Thank you for your registration to the Editorial System of Journal of Ecological Engineering

Click on the link below to finish your registration process:

https://www.editorialsystem.com/jeeng/confirm/70ad95159900746f31f3c3d2fcf6f0b0/

Following confirmation, you will be able to log in to the Editorial System available here: https://www.editorialsystem.com/jeeng/

Editorial Office of Journal of Ecological Engineering

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

New manuscript received by Editorial Office (JEENG-03231-2022-01)

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 20 Mei 2022 11.45
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

Thank you for your manuscript: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia.
The following number has been assigned to it: JEENG-03231-2022-01.

The manuscript will be checked by Editors and then sent to the Reviewers.
You will be informed by email about any further decisions on this article.

Thank you for submitting your work to our journal.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Editorial System is available here: https://www.editorialsystem.com/jeeng/

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

Decision on manuscript JEENG-03231-2022-01

2 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 2 Juni 2022 14.03
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

June 02, 2022
JEENG-03231-2022-01
Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

I am pleased to inform you that your manuscript, entitled: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia, might be accepted for publication in our journal, pending some minor changes suggested by reviewers (see below).

Please revise your paper strictly according to the attached Reviewers comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Your manuscript has been analyzed by a web-based anti-plagiarism system (iThenticate).
Please note that this email may not include all details of your article's evaluation. The full decision and file attachments are available here:
https://www.editorialsystem.com/jeeng/article/295706/view/#showDecisionLetter293938

Editor has attached the file to this decision.

Attachment:
- https://www.editorialsystem.com/dl/df/8352/48ca9c67d87d940d2de1026cd796136f/ (Editor)

Khairun Nisah <khairun.nisah@ar-raniry.ac.id> 2 Juni 2022 15.54
Kepada: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>

thank you and will be revised as soon as possible.
[Kutipan teks disembunyikan]

Journal of Ecological Engineering
ISSN 2299-8993

Decision: **accept after changes suggested by reviewer**

June 02, 2022
JEENG-03231-2022-01
Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

I am pleased to inform you that your manuscript, entitled: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia, might be accepted for publication in our journal, pending some minor changes suggested by reviewers (see below).

Please revise your paper strictly according to the attached Reviewers comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Files:
Nisah_SO.docx

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

New revision received by Editorial Office (JEENG-03231-2022-02)

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 3 Juni 2022 22.58
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

Thank you for the revision of the manuscript: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia.
The following number has been assigned to it: JEENG-03231-2022-02.

The manuscript will be rated once again by the Editors and then sent to the Reviewers.

You will be informed by email about any further decisions on this article.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Editorial System is available here: https://www.editorialsystem.com/jeeng/

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

Decision on manuscript JEENG-03231-2022-02

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 4 Juni 2022 14.46
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

June 04, 2022
JEENG-03231-2022-02
Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

I am pleased to inform you that your manuscript, entitled: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia, has been accepted for publication in our journal.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

Publishing fee has been received

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 5 Juni 2022 13.44
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

We would like to inform you that the publishing fee for the manuscript: Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia (JEENG-03231-2022-02) has been received.

Thank you for your payment!

Editorial Office of Journal of Ecological Engineering

AR-RANIRY WEBMAIL @ar-raniry.ac.id

Khairun Nisah <khairun.nisah@ar-raniry.ac.id>

Proforma invoice is available for download (JEENG-03231-2022-02)

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 8 Juni 2022 16.44
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: "Khairun Nisah khairun.nisah@ar-raniry.ac.id" <khairun.nisah@ar-raniry.ac.id>

Dear Dr. Khairun Nisah khairun.nisah@ar-raniry.ac.id,

The proforma invoice concerning the publishing of your manuscript Distribution of mercury in soil, water, and vegetable fern in a former gold mining area: Evidence from Nagan Raya Regency, Aceh Province, Indonesia (JEENG-03231-2022-02) is available for download here:
https://www.editorialsystem.com/dl/pay/26506/f3f2c3ea13d24ffc4df246da9a7418d4/

or on manuscript view page:
https://www.editorialsystem.com/jeeng/article/295706/view/payment/

Editorial Office of Journal of Ecological Engineering

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 Science and Technology, Universitas Islam Negeri Ar-Raniry, Banda Aceh 23111, Indonesia

[2]Department of Environmental Engineering, Faculty of Science 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

*Corresponding author's e-mail: khairun.nisah@ar-raniry.ac.id

ABSTRACT

~~There is a high suspiciousness on~~ The mercury contamination associated with the former intense illegal gold mining activities is suspected in the watershed of Krueng Cot Satu, Nagan Raya Regency, ~~Provinsi~~ Aceh Province, Indonesia. The aim of this study ~~is~~ was to evaluate the mercury contamination residue in the water, soil, and vegetable fern (*Pityrogramma calometanos* (L) ~~Link~~) The samples were 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~~ was 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 µg/L, 0,1447 µg/L, 2,96 % and 95-105 %, respectively. Herein, ~~we~~ it was 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 µg/g was found in soil, with the highest concentration obtained in the sample collected from the riverbank. The ~~F~~fern sample collected near the riverbank contained mercury in all ~~over~~ its parts and concentrated in the root (0.408 µg/g in the leaves, 0.276 µg/g – stalks, and 9.994 µg/g – roots). Meanwhile, the absence of mercury contamination was obtained in the leaves and stalks of the fern samples collected far from the riverbank. The roots, however, were detected with mercury contamination with the highest concentration reaching 27.660 µg/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.*

INTRODUCTION

The presence of heavy metals in environment is yet still a common problem to this date. The heavy metal could ~~be~~ originate~~d~~ from natural activities, such as volcanoes [Mandon, C.L., et.al, 2019], hot spring manifestations [Idroes, R, et.al. 2019a], erosion [Fang, H., et al, 2016], geysers [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. The ~~H~~heavy metals present in the soil could be transferred to plants, animals, and human. Heavy metal could ~~give~~ have a detrimental effect on ~~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 the aquatic ecosystem, including the sediment and aquatic organisms [Liu, 2014].

Illegal gold mining in Indonesia, as reported by others, has caused a ~~mercuy~~ mercury 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~~ that are located in Nagan Raya Regency [Zulkarnaini, 2019]. ~~Based~~ On the basis of ~~on our~~ authors' 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~~ This is owing to the fact that human activities and river flows could increase the spread of the heavy metal contamination. One of the land reclamation approaches is by utilizing plant-based biosorbents [Li et al., 2015; Zhao et al., 2018; Makarova et al., 2022]. Nonetheless, the method tends to face challenges in determining the type of suitable plant for the specific climate and geographical condition of the intended reclamation sites [Narayanasamy, Sundaram, & Vo, 2022]. Indeed, there is ~~are~~ another alternative of using a biobased adsorbent, but it could not be an option due to its high-price production [Rahmi, et al., 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~~ have 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 the 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.

MATERIALS AND METHODS

Materials

The ~~C~~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). The ~~W~~water, soil, and vegetable fern~~s~~ samples were collected from the locations described in the following sections.

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 21st ~~m~~March 2021.

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~~ labeled as point I, II, and III. The distribution of the locations was presented in a map (Figure 1). Sampling point 3 ~~were~~ was located in the ~~reiverbank~~ riverbank of Krueng Cot Satu, ~~where~~ which was ~~we~~ assumed as a final point of the mercury-contaminated wastewater ~~flew~~ flow before entering the river. Three sampling points for water sample were also determined purposively in the river flowing through the former illegal gold mining (Figure 2).

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

Soil sample collection

The ~~S~~sediment samples were collected using stainless steel scoop in the predetermined locations of former gold mining and processing. The ~~S~~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.

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

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 being 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.

Table 1. Taxonomic identity of the collected fern

Water sample collection

The water samples were collected using a 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~~ their 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 the 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).

Sample Preparation

Soil Sample Preparation

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

Fern Sample Preparation

Each fern sample ~~were~~ was cut according to its parts (leaves, stalks, and roots). Afterwards, 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 the ~~Vassel~~ vessel container, added with 25 mL distilled water, and rigorously shaken. Then, 15 mL solution of HNO_3:HCl (2:1) was added into the sample mixture, sealed, and adjusted in the ~~Vassel~~ vessel 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.

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].

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 the known concentration of standard solution.

RESULTS AND DISCUSSION

Method Validation

Linearity, limit of detection and limit of quantification

The standard solutions of Hg $(NO_3)_2$ were analyzed in concentration range of 0 - 50 µg/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 basis of ~~on the~~ the standard

deviaton of regression, the method used is ~~well~~ highly sensitive, where the LoD and LoQ calculated were 0~~,~~.0477 µg/L and 0~~,~~.1447 µg/L, respectively.

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Table 2. Linearity and uncertainty of calibration curve threshold

Precision and recovery

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

Table 3. Recovery and relative standard deviation test

Mercury content in water

Identification of the 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, it was ~~we~~ speculated that the mercury ~~migh~~ present in the river water might be 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.

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

Mercury content in soil

The presence of mercury and its content level in soil samples have been presented in Table 5. The results revealed that all samples from the three sampling locations contained mercury ~~ranged~~ ranging between 0.236 and 0.328 µg/g. The highest mercury concentration (0.328 µg/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, indicates 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].

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

The ~~M~~mercury~~-~~-containing soil is an indicator of food chain contamination, which ~~attracting~~ attracts 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, but also other heavy metals such as Cd, Cu, and Pb were found increased in area affected by artisanal gold mining [Nasir et al., 2021]. The ~~P~~people living near the contaminated locations could be exposed to mercury via wild vegetables grown therein,~~.~~ ~~O~~of which is vegetable fern which has been considered as local delicacies.

Mercury content in vegetable ferns

The contents of mercury in vegetable ferns (*P. calometanos* (L) Link) collected in this present study ~~have been~~were presented in Table 6. The presence of mercury in the ~~L~~leaves and stalks of the ferns collected from sampling points 1 and 2 ~~were~~ was not detected~~ for the presence of mercury~~. Meanwhile, the sample from point 3 (riverbank) had mercury in all over its part. ~~On contrary~~In contrast, 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 µg/L. As it 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 the soil sample from point 3 had the highest concentration as compared with others. Therefore, it is not safe to consume the ferns that 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 3.

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

~~Moreimportantly~~More importantly, ~~we~~ it was noted that the smallest mercury concentration (4.824 µg/L) in the fern roots was more than 17 times higher than the concentration in the soil sample. Hence, ~~we~~ it is stipulated 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 the 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 basis of ~~on~~ the aforementioned study [Pal & Sukul, 2022], ferns ~~absorbs~~ absorb heavy metals along with the ability to accumulate and tolerate the heavy metal.

It is ~~worthnoting~~ worth noting that *P. calometanos* is widely distributed in tropical region [Lianah, L., ~~at~~et~~.~~ 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~~et~~.~~ al., 2019]. In addition, it has also been used by the locals to reduce the concentration of arsenic in the water [Koniyo, Y.,~~at~~et~~.~~ 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 the samples collected from sampling points far from the riverbank (point 1 and 2), the mercury was only detected in its root, while ~~the mercury~~it 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, it is not safe to eat.

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 means of the 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 µg/L, 0~~,~~.1447 µg/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 µg/g) in the soil samples. The presence of mercury in soil could contaminate the wildly grown vegetables consumed by the locals, ~~of which~~including ~~is~~ vegetable ferns (*P. calometanos* (L) ~~Link~~). For the vegetable ferns growing far from the riverbank, it is safe to consume their stalks and leaves but not the roots. However, for those that grow in the riverbank area, ~~ones~~ one should be ~~caucious~~ cautious in terms of ~~on~~ the Hg contamination in the leaves and stalks. Hence, ~~we recommend~~ the ban of fern consumption is recommended if it grows in the riverbank contaminated by high concentration of Hg. More investigations need to be carried out to fully understand the pattern of Hg distribution in the plant grown in contaminated soil in order to make more comprehensive regulation.

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.

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. droes, 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.

Formatted: German (Germany)

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).

Formatted: Polish

Formatted: Polish

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.