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The effect of traditional gold mining to land degradation, mercury contamination and decreasing of agricultural productivity

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Abstract

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The destruction of natural resources and the environment has affected the level of agriculture productivity directly. The activities of illegal gold mining using Mercury cause the damage, both to agricultural and conservation areas such as Lore Lindu National Park, and it is a serious threat to the communities surrounding. This study aims to assess the degradation and productivity of cocoa, maize, and upland rice on the affected land. The type of this study is an analytical survey that used the purposive sampling technique of composite soil analyzed in the most severely damaged area. The variables are the physico-chemical properties of the soil and land productivity. Data on land degradation and productivity of selected commodities were analyzed using a descriptive approach based on the criteria of the physicochemical properties of soil. The result shows that the land in the area has been degraded. It can be seen from the pH (H_2O) of affected land was 4.41, lower (very acidic) than the pH (H_2O) of the agricultural area, which was 5.36 (slightly acidic), with high solubility of the heavy metal Al^{3+}. Loamy clay sand in the mining area and sandy loam in the agricultural area had bulkdensity of 1.9 and 1.2 g/cm^3, respectively. Productivity of agroforestry crops of cocoa, maize, and paddy (upland rice) has decreased in the last six years. Land and plants have been exposed to Hg both around the mining area and in the agricultural area. The transfer factor of the two areas was less than one (TF < 1), in a sequence, at the mine area, of Paddy Area > Maize Cropping > Cocoa Plantation > Cassava Cropping, and in the farm area, of Paddy Area > Maize Cropping > Cassava Cropping > Cocoa Plantation. There needs to be a regulation on illegal gold mining to protect the community and for sustainability of land in Lore Lindu National Park.

Keywords: land degradation; mercury contamination; productivity; protected area

Introduction

Gold mine exploration carried out traditionally by a group of people continues to increase in many areas (Basir-Cyio et al., 2017; Alphonsus et al., 2014). All regencies and cities in Central Sulawesi, even around and in the protected area, have opened uncontrolled gold mining areas. Lore Lindu National Park is also becoming the target of illegal gold mining even though the government does not allow such activity. Most of the gold mining activities are carried out traditionally and disobey environmental safety rules.

Traditional gold mining is carried out with human labor as a substitute for machines and tools and with the use of mercury as a chemical barrier between gold and stones in the ore (Nakazawa et al., 2016). The traditional gold mining area at Dongi-Dongi is around Lore Lindu National Park, and 70% of the area is located within state forest areas, both protected and conservation forests.

Mining, especially open-pit mining, leads to the mixing of overburdened rock material with topsoil, which has very low organic content, water retention, very low nutrients, and highly toxic elements, and it is unstructured. The continuous impacts of mining activities are land erosion, water and air pollution, poisoning, loss of potential biological resources, and loss of economic potential (Kinimo et al., 2018). In addition, inappropriate handling of mercury causes environmental pollution such as air, water, and land pollution (Bolaños-Álvarez et al., 2016). Several studies have proved that river water and wells adjacent to gold mining areas have a high Hg content (Malik et al., 2010). Mercury exposure to water, soil, and air can cause health problems (Nakazawa et al., 2016; Basir-Cyio et al., 2017). Maintaining the fertility of land and preserving the endemic flora in Lore Lindu National Park is of particular concern to the Central Sulawesi local government after the existence of traditional gold mining activities within the protected area. National Parks as protected areas are not only needed by a particular country but also by other countries (Xiaodong et al., 2017). Evaluation of soil quality as a result of mining activities in an area is performed to determine the intensity of changes in soil properties that directly affect plant growth (Choudhary et al., 2018;). Results of evaluating soil quality after mining are useful both to determine the existing condition of soil properties evaluated and as a basis to formulate regulation related to land-use planning. As a result of this mining, the agroforestry areas of cocoa, corn, and paddy commodities have also experienced a decline in production in the last six years. This decrease is due to the degradation of the land's physicochemical properties.

Forest encroachment by logging and plantation land clearing, which was then turned into a gold mine, began in 2015. Dongi-Dongi village is in the middle of the Lore Lindu National Park area. The community at Dongi-Dongi cleared the forest area for mining activities. Society considers that mined areas are open-access common property resources that everyone can mine. However, gold mining carried out at Dongi-Dongi has become a source of controversy between the government and miners. The government claims that the Dongi-Dongi gold mine is a protected area, so mining activities are not allowed there, while the Dongi-Dongi community claims that the mine is in an enclave, as rights to the area are given to communities around the protected areas (Kuncahyo, 2017).

This study aims to assess the condition of degraded land in mining and agricultural areas; the productivity of cocoa, corn, and paddy commodities; as well as Hg exposure levels in the urine and hair of people around Lore Lindu National Park.

Materials and Methods

Type of the study is an analytical survey on converted land of a gold mining area at the Lore Lindu National Park (Figure 1) as study area, from June to November 2017. The population of the study was the heads of families who lived in Dongi-Dongi Village of 820 people. Slovin's formula $n = N / (1 + Ne^2)$ was used to obtain a number of 268 heads of family or representatives of family members. The study used purposive and random sampling techniques.

Data collection of soil quality and content of Hg in soil was performed by analyzing one kg of soil taken at the gold processing center and in agricultural areas at depth 0–30 cm in Lore Lindu National Park. There were six soil sampling points, and from each point, six single samples were taken purposively, so there were 36 composite samples obtained. Analysis of Hg content in plant tissue was taken from the mine area around the affected agricultural area. Soil and plants samples were analyzed at the Laboratory of Natural Resources and Environment at Tadulako University using standard methods and equipment of a mercury analyzer, an AAS, a spectrophotometer, a pH meter, an oven, and a set of supporting tools in the laboratory. The information of cocoa, corn, and paddy commodities' productivity was obtained through

Sources: Lalimpala & lorelindu.info

Fig. 1. Area Study at Lore Lindu National Park (LLNP)

interviews, with questionnaire instruments compiled with secondary data from statistical data.

Respondents' characteristics included age, sex, education level, occupation, nutritional status (body mass index) and number of family members, obtained directly from the questionnaire.

Data analysis. Data of physicochemical properties of soil and content of Hg of soil and plants were based on criteria justification for each element or indicator. Patterns of productivity decrease of cocoa, corn, and paddy were obtained using the simple linear regression technique. Meanwhile, to investigate whether or not the plant was accumulative, Transfer Factor [(TF) = C_p C_s] was used, where C_p was the concentration of Hg in plant tissue and C_s was the concentration of Hg in the soil solution.

Results

A. Soil chemical properties

Analysis results of soil physicochemical properties from the mine and surrounding land and from the agricultural area are presented in Table 1 for each criterion. The criteria show the change of physicochemical properties of soil before and after changing from agricultural area into mining area.

(a) pH of Soil

Based on the results of laboratory analysis, the pH of soil in the former gold mine land and in the agricultural area in Dongi-Dongi at Lore Lindu National Park area ranges between 4.41 and 5.36 (classified as very acidic to acidic). This situation is due to the complex exchange on the colloidal surface, and the soil solution is dominated by acid cations, mainly Al^{3+} cations, resulting in very low soil pH. Increase of Al^{3+} ion concentration is positively correlated with H^+ ions and is inversely proportional to soil pH. The result of soil chemical analysis shows that saturation of Al^{3+} is very high, and the mining area's soil pH (H_2O) of 4.41 (highly acidic) is lower than the soil pH (H_2O) in the agricultural area of 5.36 (slightly acidic).

(b) C-organic Content

Soil's C-organic content in the gold mining area and the agricultural area in Dongi-Dongi ranges from 3.19% to 4.67% (low to high). In the gold mine area, all vegetation of organic material sources is gone, resulting in C-organic decrease. Content of C-organic of 3.18% in the mining area is lower than the 4.67% in the agricultural area. Vegetation produces organic matter on agriculture land as the main contributor to increasing soil C-organic. Table 1 shows that the agricultural area, with higher organic materials, has lower Al^{3+} ion content and higher soil pH than the gold mining area.

(c) Content of Total N and C/N Ratio

Nitrogen (N) in the soil is generally sourced from organic material debris. The low N content (0.20%) in the mining area compared to the agricultural area (0.43%) indicates a minimal nitrogen source and the existence of organic matter with a high C/N ratio in the mining area. The analysis indicates that the C/N ratios in the mining area and the agricultural area around Lore Lindu National Park are classified as moderate to high (10.53–14.43) and become an indicator of whether or not organic matter is easily decomposed. The total N content in the agricultural area is sourced from plant debris decomposed by land microorganisms.

Table 1. Soil Indicators in gold mine land and agricultural area at Lore Lindu National Park

No	Indicator	Mine land	Criteria	Agricultural area	Criteria
1	pH H_2O	4.41	Very Acid (va)	5.36	Acid
2	C-organic (%)	4.67	High	3.19	High
3	N total (%)	0.43	Medium	0.20	Low
4	C/N ratio	10.53	Medium	14.43	Medium
5	P available (ppm)	21.58	Medium	1.43	Very Low
Bases Cations Exchanged					
6	Ca^{++} (me/100 g)	1.21	Very Low	2.38	Low
	Mg^{++} (me/100 g)	0.42	Very Low	1.52	Medium
	K^+ (me/100 g)	0.47	Medium	0.39	Low
	Na^+ (me/100 g)	0.07	Very Low	0.09	Very Low
7	CEC (me/100 g)	4.35	Very Low	4.90	Very Low
8	Saturation Bases (%)	50.32	Medium	87.75	Very High
9	Aluminum Saturation (%)	49.71	Very High	12.25	Low

Source: The result of soil analysis in the laboratory (2017)

(d) Content of P-available

Content of phosphorus (P) available is determined by many factors. Available phosphorus (P-available) in the gold mining area and the agricultural area in Dongi-Dongi ranges from 1.43 ppm to 21.58 ppm (classified as very low to medium). Low content of P-available in the mining area is due to the stripping of the top soil layer, as the soil deep is required for seasonal crops' growth. In the agricultural area, the content of P ions is higher than at the mine (21.58 ppm). This condition is due to the intact layer of top soil, so P sourced from the parent material (rock/mineral) is high. The solubility level of P-inorganic and P-organic in the soil is generally very low, so P absorbed by plants is low as well.

(e) Cations Exchanged

The results of base cations analysis on the gold mining area and the agricultural area in Dongi-Dongi show that base cations can be exchanged ranging from very low to low. Base cations, including Ca^{++} (1.21–2.38 me/100 g) and Mg^{++} (0.42–1.52 me/100 g) are classified as very low to moderate; K^{+} (0.39–0.47 me/100 g) is classified as low to moderate; and Na^{+} (0.07–0.09 me/100 g) is classified as low. The content of base cations in the mining area is lower than that in the agricultural area.

(f) Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) in the gold mining area and the agricultural land in Dongi-Dongi is between 4.35 and 4.90 me/100 g (very low), with CEC in the gold mining area lower than CEC in the agricultural area. The value of soil CEC indicates soil's capability to reconstitute base ions located on the surface of the soil colloidal complex.

(g) Bases Saturation and Aluminum Saturation

Based on the results of laboratory analysis and the calculation of the number of cations, bases saturation in the gold mining area and the agricultural area at Dongi-Dongi ranges from 50.32 to 87.78% (classified as very low to very high), and Al saturation ranges from 12.25 to 49.71% (low to very high). All these indicators indicate that bases and aluminum saturation in the mine area is lower than that in the agricultural area.

B. Soil Physical Properties

Soil texture is one of the major indicators of soil's physical properties considered when investigating the potential level of land. Several results of analysis of soil's physical properties (texture and specific gravity of volume) are presented in Table 2.

The results of laboratory analysis indicate that soil in the gold mining area and the agricultural area in Dongi-Dongi is predominantly sand fraction. Based on the percentage of each fraction of soil, soil texture in the mining area is included in the category of loamy clay sand, while soil in the agricultural area is categorized as sandy loam. The high fraction of sand in the traditional gold mining area results from the process of land degradation due to the excavation of raw materials at the gold mine to be processed by miners.

Another major physical indicator is bulk density. The result of bulk density analysis on two different types of land utilization indicates that bulk density in the gold mining area Is higher (1.9 g/cm^3) than that in the agricultural area (1.2 g/cm^3). The value of bulk density is an indicator of whether or not certain land is hard to process or plow.

C. Mercury Content in Soil and Plants

Results of analysis on soil and plant samples surrounding mining and agricultural areas at Lore Lindu National Park (LLNP) for four types of plants are presented in Table 3.

The data in Table 3 indicate that the closer the mining area is, the higher the concentration of Hg in soil and plants. The area where gold is separated from rocks has the highest Hg concentration of 387.3 ppm, followed by the corn plantation (0.41 ppm), paddy fields (0.38 ppm), and cassava field

Table 2. Results of analysis on physical properties of former mining area and agricultural area

No	Soil Fraction	Gold Mining Area	Agricultural Area
1	Bulk density (g/cm^3)	1.9	1.2
2	Loam (%)	13.48	11.97
3	Clay (%)	2.48	8.93
4	Rough Sand (%)	16.96	3.10
5	Medium Sand (%)	57.79	3.00
6	Fine Sand (%)	9.29	73.00
7	Sand (Total) (%)	84.04	79.10
8	Texture Class	Loamy Clay Sand	Sandy Loam

Source: Result of soil texture analysis at LASDAL Laboratory of Tadulako University (2017)

Table 3. Hg content in soil and plants in mining and agricultural areas at LLNP

Number	Sampling Point	Mining Area Hg (ppm)		TF Soil-Plant	Agricultural area Hg (ppm)		TF Soil-Plant
		Soil	Plant		Soil	Plant	
1	Maize Cropping	0.41	0.11	0.27	0.15	0.03	0.20
2	Paddy Area	0.38	0.18	0.47	0.11	0.05	0.45
3	Cassava Cropping	0.33	0.03	0.10	0.13	0.02	0.15
4	Cocoa Plantation	0.17	0.02	0.12	0.09	0.01	0.11
5	Settlement	0.29			0.18		
6	Gold Processing Area	387.3					

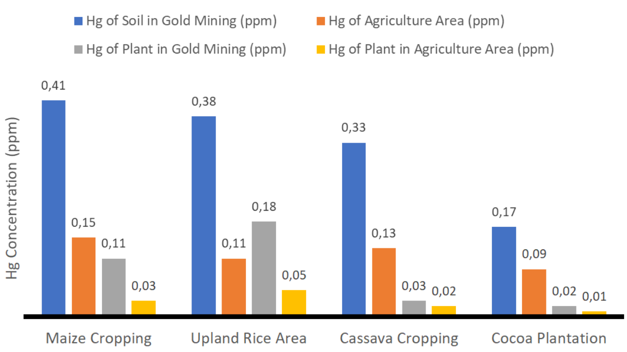

Fig. 2. Soil and plant Hg concentration in gold mining and agricultural area at Lore Lindu National Park

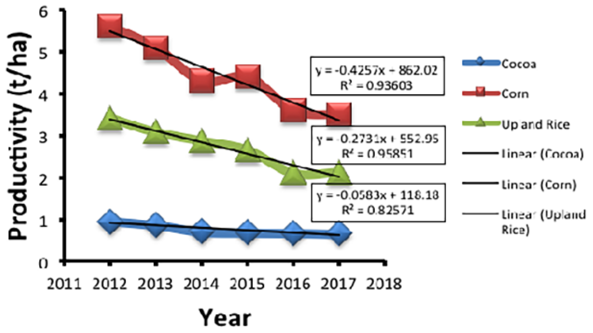

Fig. 3. Productivity of cocoa, corn, and paddy agroforestry system

(0.33 ppm). Comparison between soil and plant Hg in mining and agricultural areas is presented in Figure 2.

Concentration of Hg in the soil in the four planting areas is highest in the corn cultivation area, followed by paddy field, cassava, and cocoa. The concentration of Hg in the soil ranges from 0.17 to 0.41 ppm, but those categorized as critical are corn, paddy fields, and cassava with values of 0.3 ppm. The further the plantation area from the mining area, the lower the mercury levels in the soil or plant tissue. On plantations near the mining area, the concentration of Hg in plants is above 0.03 ppm (critical), while outside the mining area, the concentration is lower at 0.01 ppm (normal).

The process of inclusion of Hg from the soil solution in plant tissue is assumed to be a linear relationship, so if the concentration of mercury in the soil solution increases, mercury that will be absorbed by plant roots will increase as well. This follows equation of Transfer Factor (TF): $TF = C_p$ C_s where C_p and C_s are Hg concentrations in the plant solution and soil, respectively. Based on Table 3, TF in both the mining area and the agricultural area is < 1.0; in sequence, in the mining area, Paddy Area > Maize Cropping > Cocoa Plantation > Cassava Cropping, while in the agricultural area, Paddy Area > Maize Cropping > Cassava Cropping > Cocoa Plantation.

D. Production of Agroforestry Commodities

The agricultural area within the protected area and its surroundings reaches 750 Ha, but approximately 232.8 ha are used for agroforestry activities, mainly growing cocoa but also corn and paddy (Muhardi, 2017). Over the past three years, cocoa commodity productivity has continued to decline significantly. The cocoa production data obtained from farmer respondents are presented in Figure 3.

The results of field data collection show a decline in the productivity of cocoa, corn, and paddy in the agroforestry system around Lore Lindu National Park for the last six years. The decrease in agroforestry agricultural productivity indicates degradation in land condition, so the land's carrying capacity for growth and crop production is not at its maximum.

E. Characteristics of Respondents

The subjects of this study had various characteristics. Differences in age, educational level, and nutritional status conditions determine the degree to which the families of

Table 4. Characteristic of miner and farmer respondents

Characteristics	Number of Respondents (n) = 286	%
Age (Years)		
≤ 20	58	20.3
21–35	133	46.5
36–50	83	29.0
≥ 51	12	4.2
Gender		
Men	219	76.6
Women	67	23.4
Occupation		
Miner	197	68.9
Farmer	89	31.1
Education		
Elementary School (SD)	177	61.9
Junior High School (SMP)	92	32.2
High School (SMA)	17	5.9
Number of Family Members (alive)		
2–3	27	9.4
4–5	174	60.8
≥ 6	85	29.7
Nutritional Status (IMT)		
Malnutrition	128	44.8
Normal Nutrition	103	36.0
Over Nutrition	55	19.2

miners and farmers are low. The characteristics of respondents are presented in Table 4.

Based on the data presented in Table 4, the largest group of respondents (46.5%) was aged 21–35 years, and 20.3% of respondents were aged 58 years. 76.6% of respondents were men, and those who worked as miners were 68.9%. Thus, only about 7.7% of people worked in the agricultural area. The education level of the respondents is very low because most (61.9%) of them were elementary school graduates and only 5.9% of them had graduated senior high school. This indicates that the high number of dropouts in the location of the study is due to the high attractiveness of traditional gold mines. Economically, farmers are unable to generate as much income as traditional gold miners do, so many of the farmers change professions (Drew et al., 2018). Approximately 60.8% of miners had four or five family members, and 44.8% were malnourished. The low level of education and the great burden imposed by the families caused a disproportionate amount of income to go to the needs of the families. The malnutrition status is an indicator of the inability of a family to meet its need for nutritious food (Choe et al., 2018).

Discussion

The results indicate that gold mining activities generate environmental impacts indicated by decreasing soil quality both physically and chemically. Soil reaction [pH (H_2O)] in gold mining areas is lower than that in the agricultural area. High soil acidity or low pH indicates low availability of nutrients that can be absorbed by plants. Low pH of fewer than 5.5 hampers roots' growth and plants' metabolism, as it promotes the accumulation of toxic metals, such as aluminum or manganese, phosphorus fixation, and N-fixing bacteria population declines (Sheoran et al., 2010).

High concentrations of Al^{3+} ions and H^+ ions can decrease soil pH of both pH (H_2O) and pH (KCl) (Zioła-Frankowska & Frankowski, 2018). Acidic soil's Al^{3+} solubility, which stimulates the concentration and activity of H^+ ions in soil solution, is very high (Zioła-Frankowska & Frankowski, 2018), causing soil pH to decrease (Murano et al., 2017; Husson et al., 2018; Vlaskin et al., 2018; Ou et al., 2017). Soil acidity (pH) is a leading indicator of various chemical activities occurring in soil (Guillaume et al., 2016). Organic material (C-organic) in the mining area was very low (1.29%), and N-total was 0.12 %. The results of this study are in line with the result of a study (Eludoyin et al., 2017) saying that gold mining activity causes land degradation and loss of soil nutrients. Other studies have also proved that C-organic contained in the soil in mining areas decreases (Mushia et al., 2016). Likewise et al. (2001) pointed out that land surface in a mining area experiences physical property degradation and significant loss of organic matter and nutrients, resulting in a decrease of soil productivity. The low organic matter content is caused by low vegetation density, slow decomposition rate, and debris accumulation due to gold mining. The variation of C-organic content depends on the organic matter of the decomposition that contributes to the soil (Kučerík et al., 2018). The higher the organic matter in soil, the better the soil's physical properties (García-Díaz et al., 2018).

Organic materials improve soil structure to result in high porosity, which can reduce the occurrence of oxygen depletion (Nierop et al., 2017). Good air circulation increases microorganism activities, so a number of dissolved heavy metals can be chelated, resulting in the concentration and activity of the metals decreasing (Chen et al., 2018). The carbon/nitrogen ratio (C/N-ratio) reflects the decomposition level of organic matter (Chen et al., 2018) as a source of nitrogen for soil (Heinz & Zak, 2018), which can increase nitrogen availability in soil for plant growth. Nitrogen ions that can be absorbed by plants are NH_4^+ and NO_3^- (Latifah et al., 2017; Cheng et al., 2018; Yoshioka et al., 2018). In oxidative conditions, Nitrogen dominance in an agricultural area is in the form of nitrate ions (NO_3^-), and in reductive conditions, nitrogen dominance is in the form of NH_4^+ ions (Sinha Majumdar et al., 2018). The availability of P nutrients is determined by the solubility level of Al^{3+}. P-available is generally in the form of $H_2PO_4^+$, HPO_4^{2+}, and PO_4^{3+}, although dominant ions are in the form of $H_2PO_4^+$ and HPO_4^{2+} (Saleh Bairq et al., 2018).

The higher the P- availability in soil solution, the higher the concentration of P solution available to plants (Husson et al., 2018; Garcia-Perez-de-Lema et al., 2017). The low availability of P is due, in addition to its low P content, also to the fixation of Al^{3+} ions in the form of Al-P and Fe^{3+} ions in the form of Fe-P, which is minimally available for plants (Arai & Livi, 2013; Saleh Bairq et al., 2018; Liu et al., 2018). Soil's ability to supply nutrients depends on soil CEC in exchanging bases-ion. Land with low CEC promotes the leaching process, so base ions exchanged are accumulated in subsoil layers (Jho et al., 2015), although bases have high adhesion capability on the soil colloidal surface complex (Kulikowska et al., 2015). The narrow colloidal surface and the acidic soil pH are two components affecting each other (Khaledian et al., 2017) that have a correlation with cation exchange capacity (CEC) (Liddicoat et al., 2018; Shiri et al., 2017).

Ionic Al in extremely weathered soil is dominant in colloid exchange complexes with strong fixation capability (Walton et al., 2007). In addition to chemical properties, physical properties also determine the potential of land. Soil texture and bulk density also determine whether or not land gives maximum production. Gold mining activities have damaged most of the land surrounding Lore Lindu National Park. Recovery of land degraded due to gold mining activities requires large and technically difficult investments (de Jong, Salm, & Schmitz, 2017). Mining activities tamp the soil, so it becomes more difficult to process. The higher the bulk density of land, the more difficult the land is to process. If bulk density is higher than 1.6 g/cm^3, land is unsuitable to be used as agricultural area (Yevtushenko et al., 2016). Gold mining activity has generated many negative impacts. Numerous studies have shown that persistent mercury exposure can lead to toxicity and specific symptoms in humans (Hong et al., 2012), but the use of mercury in traditional gold mines remains high.

Economic need is a main factor for the community around the protected area in changing profession from farmers to gold miners. Negative environmental impacts due to the use of mercury have never been considered by miners, especially in traditional mines (Gibb & O'Leary, 2014). The implications of this study provide clear evidence and encouragement for local authorities to take an unequivocal act of closing the Lore Lindu National Park area for mining activity. Local government should immediately recover the damaged land by restoring the land fertility in former mining area. The low education of miners and farmers is the cause of their lack of knowledge on environmental sustainability.

The amount of land and number of plants exposed to mercury tend to increase around the gold mining activity at Lore Lindu National Park. This can be seen from mercury concentration in soil and plant tissues among corn, paddy, cassava, and cocoa crops. The farther the distance from the gold mining processing point, the lower the concentration of Hg in soil and plants. This decrease is due to Hg's being unstable in nature and easily carried by wind and both surface and capillary water (Karásek et al., 2018). Hg concentration exposure in plants provides a threat of toxicity for humans who consume agricultural products that have been exposed to Hg (Azevedo et al., 2018). The higher concentration of Hg in the soil is assumed to cause higher concentration of Hg in plants via the soil's transfer factor (TF) to the plant. If the value of TF > 1, then the plant has the ability to accumulate Hg; if TF is close to value of 1, then the plant is not affected by Hg, and if the value of TF < 1 then the plant metabolically has the ability to prevent Hg in the soil from entering (uptake) the plant's tissue (Tamene Fite Duressa & Seyoum Leta, 2015).

Productivity of cocoa, maize, and paddy in the agroforestry plantation system has decreased in the past six years. The negative trend is seen to be significant from the correlation coefficient (r) of cocoa (0.93), maize (0.95), and paddy (0.82). The decrease in productivity of these three commodities is due to the land condition, which no longer has suitably fertile soil for plants to grow. The degradation of soil fertility has a direct effect on crop productivity (Kafesu et al., 2018a, 2018b). Economically, the agricultural sector is unable to generate as much income as it earned from traditional gold mines, which causes farmers to change their profession (Drew et al., 2018).

The amount of family burden also contributes to the unbalance between the amount of income and the needs of families, especially food fulfillment. Malnutrition is an indicator of a family's inability to meet its need for nutritious food (Choe et al., 2018). Given the low awareness of miners and farmers about their health, the use of mercury in the process of separating gold content from raw materials received no serious attention. Although several studies have shown that increased exposure to mercury can lead to specific toxicity and symptoms (Hong et al., 2012) mercury continues to be used in traditional gold mines (Gibb & O'Leary, 2014).

Conclusion

Lore Lindu National Park is a protected area that has ecological functions and should be spared from economic fulfillment. Land damage is a result of the activities of traditional gold mining that does not consider sustainability. Local communities and some local migrants have made Lore Lindu National Park a source of income for their families' economic needs. Land damage has occurred both physically and chemically, so the agricultural area has changed; even the productivity of land that is still used for agricultural activities has decreased. The commodities of cocoa, corn, and paddy have had a declining trend in the last six years. The high degree of acidity and high levels of aluminum and environmental pollution derived from mercury are serious threats to the sustainability of the land resource, particularly the Lore Lindu National Park. Soil and plants have been exposed to Hg, including corn, paddy, potatoes, and cocoa crops. The concentration of Hg in soil solution in the mining area is classified as critical (Hg > 0.3 ppm), as is that in plant tissue, which is Hg > 0.03 ppm. Strategic regulation is required to protect people from mercury exposure; to maintain the agricultural area and plantations, especially agroforestry farming, from land conversion to traditional gold mining areas; and to minimize environmental damages and threats to Lore Lindu National Park, the lungs of the world.

Conflicts of Interest

The researchers declare that there are no competing interests in this study.

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References

Akala, V. A. & Lal, R. (2001). Soil organic carbon pools and sequestration rates in reclaimed minesoils in Ohio. *Journal of Environmental Quality, 30 (6),* 2098–2104.

Alfonsus, H. & Sukmana, A. (2014). Traditional gold mining correlation against socio-economic situation: Cases in Madina District (North Sumatra). In: *Balai Penelitian Kehutanan Aek Nauli*, 1:1–17. Medan: Balai Penelitian Kehutanan Aek Nauli.

Arai, Y. & Livi, K. J. (2013). Underassessed phosphorus fixation mechanisms in soil sand fraction. *Geoderma, 192*, 422–29. https://doi.org/10.1016/j.geoderma.2012.06.021.

Basir-Cyio, M., Takanobu Inoue, M., Anshary, A., Kawakami, T., Rahman, N., and Golar, B. (2017). Impact of the traditional gold mine management on public health and agricultural land: A study of traditional gold mining in Poboya, Sausu and Dongi-Dongi Village, Central Sulawesi, Indonesia. *Journal of Food, Agriculture and Environment, 15 (3&4),* 115–22.

Bolaños-Álvarez, Y., Alonso-Hernández, C. M., Morabito, R., Díaz-Asencio, M., Pinto, V. & Gómez-Batista, M. (2016). Mercury contamination of riverine sediments in the vicinity of a mercury cell chlor-alkali plant in Sagua River, Cuba. *Chemosphere, 152*, 376–82. https://doi.org/10.1016/j.chemosphere.2016.03.025

Chen, H., Zhao, Y., Yang, Q. & Yan, Q. (2018). Preparation of poly-ammonium/sodium dithiocarbamate for the efficient removal of chelated heavy metal ions from aqueous environments. *Journal of Environmental Chemical Engineering*, https://doi.org/10.1016/j.jece.2018.03.029.

Chen, X., Xu, Y., Gao, H., Mao, J., Chu, W. & Thompson, M. L. (2018). Biochemical stabilization of soil organic matter in straw-amended, anaerobic and aerobic soils. *Science of The Total Environment, 625*, 1065–73. https://doi.org/10.1016/j.scitotenv.2017.12.293.

Cheng, Y., Li, P., Xu, G., Li, Zh., Wang, T., Cheng, Sh., Zhang, H. & Ma, T. (2018). The effect of soil water content and erodibility on losses of available nitrogen and phosphorus in simulated freeze-thaw Conditions. *CATENA,* 166, 21–33. https://doi.org/10.1016/j.catena.2018.03.015.

Choe, Y.-R., Joh, J. Y., Sunwoo, D. & Kim, Y.-P. (2018). Interaction between frailty and nutritional status on mortality and long-term hospitalization in older koreans: A retrospective analysis of data from the 2008 survey on health and welfare status of the elderly in Korea. *Archives of Gerontology and Geriatric,s 76,* 106–13. https://doi.org/10.1016/j.archger.2018.01.011.

Choudhary, M., Jat, H. S., Datta, A., Yadav, A. K., Sapkota, T. B., Mondal, S., Meena, R. P., Sharma, P. C. & Jat, M. L. (2018). Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. *Ap-*

plied Soil Ecology, 126, 189–98. https://doi.org/10.1016/j.apsoil.2018.02.027.

Drew, J., Dollery, B. E. & Blackwell, B. D. (2018). A square deal? Mining costs, mining royalties and local government in New South Wales, Australia. *Resources Policy, 55*, 113–22. https://doi.org/10.1016/j.resourpol.2017.11.004.

Eludoyin, A. O., Ojo, A. T., Ojo, T. O. & Awotoye, O. O. (2017). Effects of artisanal gold mining activities on soil properties in a part of Southwestern Nigeria. Edited by Thaddeus Nzeadibe. *Cogent Environmental Science, 3 (1).* https://doi.org/10.1080/23311843.2017.1305650.

García-Díaz, A., Marqués, M. J., Sastre, B. & Bienes, R. (2018). Labile and stable soil organic carbon and physical improvements using groundcovers in vineyards from Central Spain. *Science of The Total Environment, 621,* 387–97. https://doi.org/10.1016/j.scitotenv.2017.11.240.

Garcia-Perez-de-Lema, D., Madrid-Guijarro, A. & Martin, D. Ph. (2017). Influence of University–firm governance on SMEs innovation and performance levels." *Technological Forecasting and Social Change, 123,* 250–61. https://doi.org/10.1016/j.techfore.2016.04.003.

Gibb, H. & O'Leary, K. G. (2014). Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: A comprehensive review. *Environmental Health Perspectives*, https://doi.org/10.1289/ehp.1307864.

Guillaume, Th., Maranguit, D., Murtilaksono, K. & Kuzyakov, Y. (2016). Sensitivity and resistance of soil fertility indicators to land-use changes: New concept and examples from conversion of Indonesian rainforest to plantations. *Ecological Indicators, 67,* 49 -57. https://doi.org/10.1016/j.ecolind.2016.02.039.

Heinz, M. & Zak, D. (2018). Storage effects on quantity and composition of dissolved organic carbon and nitrogen of lake water, leaf leachate and peat soil water. *Water Research, 130,* 98–104. https://doi.org/10.1016/j.watres.2017.11.053.

Hong, Y.-S., Kim, Y.-M. & Lee, K.-F. (2012). Methylmercury exposure and health effects. *Journal of Preventive Medicine and Public Health, 45 (6),* 353–63. https://doi.org/10.3961/jpmph.2012.45.6.353.

Jong, M. J., de, Salm, C. & Schmitz, J. (2017). Observations on the recovery of hot carrier degradation of hydrogen/deuterium passivated nMOSFETs. *Microelectronics Reliability,* 76–77, 136–40. https://doi.org/10.1016/j.microrel.2017.07.038.

K**haledian, Y., Brevik, E. C., Pereira, P., Cerdà, A., Fattah, M. A. & Tazikeh, H.** (2017). Modeling soil cation exchange capacity in multiple countries. *CATENA, 158,* 194–200. https://doi.org/10.1016/j.catena.2017.07.002.

Kinimo, K. Ch., Yao, K. M., Marcotte, S., Kouassi, N. L. B. & Trokourey, A. (2018). Distribution trends and ecological risks of arsenic and trace metals in wetland sediments around gold mining activities in Central-Southern and Southeastern Côte d'Ivoire. *Journal of Geochemical Exploration,* 190, 265–80. https://doi.org/10.1016/j.gexplo.2018.03.013.

Kučerík, J., Tokarski, D., Demyan, M. S., Merbach, I. & Siewert, Ch. (2018). Linking soil organic matter thermal stability with contents of clay, bound water, organic carbon and nitrogen. *Geoderma, 316,* 38–46. https://doi.org/10.1016/j.geoderma.2017.12.001.

Latifah, O., Ahmed, O. H. & Majid, N. M. A. (2017). Enhancing nitrogen availability from urea using clinoptilolite zeolite. *Geoderma,* 306, 152–59. https://doi.org/10.1016/j.geoderma.2017.07.012.

Li, J., Wen, Y., Li, X., Li, Y., Yang, X., Lin, Zh., Song, Zh., Cooper, J. M. & Zhao, B. (2018). Soil labile organic carbon fractions and soil organic carbon stocks as affected by long-term organic and mineral fertilization regimes in the North China Plain. *Soil and Tillage Research, 175*, 281–90. https://doi.org/10.1016/j.still.2017.08.008.

Liao, N., Li, Q., Zhang, W., Zhou, G., Ma, L., Min, W., Ye, J. & Hou, Zh. (2016). Effects of biochar on soil microbial community composition and activity in drip-irrigated desert soil." *European Journal of Soil Biology, 72,* 27–34. https://doi.org/10.1016/j.ejsobi.2015.12.008.

Liddicoat, C., Bi, P., Waycott, M., Glover, J., Breed, M. & Weinstein, Ph. (2018). Ambient soil cation exchange capacity inversely associates with infectious and parasitic disease risk in Regional Australia. *Science of The Total Environment, 626,* 117–25. https://doi.org/10.1016/j.scitotenv.2018.01.077.

Liu, H., Yuan, P., Liu, D., Bu, H., Song, H., Qin, Z. & He, H. (2018). Pyrolysis behaviors of organic matter (OM) with the same alkyl main chain but different functional groups in the presence of clay minerals. *Applied Clay Science,* 153, 205–16. https://doi.org/10.1016/j.clay.2017.12.028.

Malik, R. N., Husain, S. Z. & Nazir, I. (2010). Heavy metal contamination and accumulation in soil and wild plant species from industrial area of Islamabad, Pakistan. *Pak. J. Bot., 42 (1),* 291–301.

Mushia, N., Ramoelo, A. & Ayisi, K. (2016). The impact of the quality of coal mine stockpile soils on sustainable vegetation growth and productivity. *Sustainability, 8 (12),* 546. https://doi.org/10.3390/su8060546.

Nakazawa, K., Nagafuchi, O., Kawakami, T., Inoue, T., Yokota, K., Serikawa, Y., Cyio, B. & Elvince, R. (2016). Human health risk assessment of mercury vapor around artisanal small-scale gold mining area, Palu City, Central Sulawesi, Indonesia. *Ecotoxicology and Environmental Safety,* 124, 155–62. https://doi.org/10.1016/j.ecoenv.2015.09.042.

Nierop, K. G. J., Reichart, G.-J., Veld, H. & Sinninghe Damsté, J. S. (2017). The influence of oxygen exposure time on the composition of macromolecular organic matter as revealed by surface sediments on the Murray Ridge (Arabian Sea). *Geochimica et Cosmochimica Acta, 206,* 40–56. https://doi.org/10.1016/j.gca.2017.02.032

Ou, Y., Rousseau, A. N., Wang, L. & Yan, B. (2017). Spatio-temporal patterns of soil organic carbon and pH in relation to environmental factors - A case study of the black soil region of Northeastern China. *Agriculture, Ecosystems & Environment, 245*, 22–31. https://doi.org/10.1016/j.agee.2017.05.003

Poulin, J. & Gibb, H. (2008). Mercury: Assessing the environmental burden of disease at national and local levels. Editor, Prüss-Üstün A. WHO Environmental Burden of Disease Series No. 16. Geneva: World Health Organization.

Saleh, B., Ali, Z., Li, R., Li, Y., Gao, H., Sema, T., Teng, W., Kumar, S. & Liang, Zh. (2018). New advancement perspectives of chloride additives on enhanced heavy metals removal and phosphorus fixation during thermal processing of sewage sludge. *Journal of Cleaner Production*, March. https://doi.org/10.1016/j.jclepro.2018.03.276

Sembiring, S. (2008). Soil chemical and physical properties of the Ex-Bauxite Mining Site at Bintan Island, Riau. *Info Hutan, V (2),* 123–34.

Sheoran, V., Sheoran, A. S. & Poonia, P. (2010). Soil reclamation of a bandoned mine land by revegetation: A review. *International Journal of Soil, Sediment and Water, 3 (2),* 1–21.

Sinha Majumdar, S., Alexander, A.-M., Gawade, P., Celik, G. & Ozkan, U. S. (2018). Effect of alumina incorporation on the sulfur tolerance of the dual-catalyst aftertreatment system for reduction of nitrogen oxides under lean conditions. *Catalysis Today*, https://doi.org/10.1016/j.cattod.2018.01.027

Vlaskin, M. S., Dudoladov, A. O., Buryakovskaya, O. A. & Ambaryan, G. N. (2018). Modelling of aluminum-fuelled power plant with steam-hydrogen enthalpy utilization. *International Journal of Hydrogen Energy, 43 (9),* 4623–31. https://doi.org/10.1016/j.ijhydene.2018.01.023

Walton, J. R., Diamond, T. H., Kumar, S. & Murrell, G. A. C. (2007). A sensitive stain for aluminum in undecalcified cancellous bone. *Journal of Inorganic Biochemistry, 101 (9),* 1285–90. https://doi.org/10.1016/j.jinorgbio.2007.06.006

Yevtushenko, T. V., Tonkha, O. L. & Pikovskaa, O. V. (2016). Changes in balk density and porosity of chernozem typical under different cultivation systems. *Annals of Agrarian Science, 14 (4)*, 299–302. https://doi.org/10.1016/j.aasci.2016.09.005

Yoshioka, T., Wiedenbeck, M., Shcheka, S. & Keppler, H. (2018). Nitrogen solubility in the deep mantle and the origin of earth's primordial nitrogen budget. *Earth and Planetary Science Letters, 488,* 134–43. https://doi.org/10.1016/j.epsl.2018.02.021

Zioła-Frankowska, A. & Frankowski, M. (2018). Speciation analysis of aluminium in plant parts of *Betula pendula* and in soil. *Journal of Environmental Sciences, 65*, 153–61. https://doi.org/10.1016/j.jes.2017.03.021

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