Pollution and contamination level of Cu, Cd, and Hg heavy metals in soil and food crop

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Abstract

We aimed to assess and observe the accumulation of Cu, Cd, and Hg heavy metals on land and the contamination of plant tissues in Grand Forest Park, Palu, Indonesia, and its surrounding areas. The method used was a mix between survey and investigation, integrating data on research findings from before 2013 to 2016 with data from 2018. The data were analyzed using a correlation test, and descriptive statistics are presented in the form of tables and graphs. The results show that the highest concentration of Hg was found in the Poboya processing area (575.16 ppm) in 2013, though it gradually decreased to 287.64 ppm in 2018. The results of the Spearman's rank test at the $\alpha 0.05$ level between average Cu land and Cu plant concentrations show that the obtained value (r) was 0.52 with a rho (ρ) of 0.13, which is not significant ($\rho 0.13 > 0.05$), while for Cd and Hg metals, the obtained r values were 0.88 and 0.86, respectively. These two metals showed significant correlations between concentrations of Cd and Hg on land and Cd and Hg in plant tissues (both $\rho 0.001 < 0.05$). Specifically, the transfer factor (TF) value at the sampling sites of the Grand Forest Park area, Ngatabaru, and PBY from the average of various Hg concentrations in plants was much higher than the TF values of Cu and Cd, specifically being $Hg > Cd = Cu$ or $0.61 > 0.17 = 0.17$.

Keywords Pollution · Contamination · Heavy metal · Grand Forest Park

Introduction

Soil, as a highly dynamic and complex natural body of time and space, is part of land, which includes agricultural land and human settlement areas. Two main areas around Grand Forest Park in Central Sulawesi Province, Indonesia have been contaminated by the heavy metal mercury as a result of traditional gold mining activities and the accumulation of copper and cadmium. Residential settlements fewer than 0.5 km away from and agricultural areas adjacent to Grand Forest Park are particularly vulnerable to the effects of this pollution, including heavy metal contamination in

agricultural plants, which is highly dangerous to human health. Illegal traditional mining activities have become a source of pollution worldwide, affecting human health (Frækaland Vangsnes 2018; Razanamahandry et al. 2018). The degradation of physical, chemical, and geo-ecological properties due to excavation and the separation process of gold from rocks using mercury are currently poorly controlled (Martinez et al. 2018; Mashyanov et al. 2017; Park et al. 2014). The amount of mercury used by mineworkers around Grand Forest Park in the administrative area of Paly City and Sigi Regency was 500 g per drum on average. The number of drums in 2016 was 19,617 (Nakazawa et al. 2016), increasing by 10% to 21,579 in 2017. If each drum uses 500 g Hg/operation on average and operates three times daily, the amount of mercury used is 1500 g/day. Multiplying this by 21,579 drums results in 32,362.5 kg/day, a dangerous amount that threatens the safety of the environment, humans, and other living things. The increasing number of drums and amount of mercury used in illegal traditional gold mining is caused by two main factors: (1) the increase in the number of mine workers and (2) the expansion of mining

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areas (Jonek-Kowalska 2018). The number of mine workers around Grand Forest Park continues to increase, from 15,231 people in 2016 to 19,651 people in 2017. In 2017, there were 2120 raw-material diggers and miners, 11,329 drum workers, 1423 barrel workers, and 4799 material transport workers. The expansion of mining areas has stretched from the north in Palu City to the south in Sigi Regency. The increase in the number of worker and the expansion of traditional gold mining areas has resulted in a drastic increase in the need for mercury, which in turn has led to agricultural land, farms, settlements, and watershed areas being affected by mercury from both drum waste and barrels (Brown 2016; Spiegel et al. 2018). The heavy metal mercury moves to affected areas through two flow patterns according to Li et al. (2018) and Zhan et al. (2016): (1) the entry of surface water into the soil through infiltration and percolation and (2) the flow of surface water carrying mercury into the river. The most dominant pattern, surface water infiltration, affects agricultural land, plantations, and settlements (Gulley 2017; Saniewska et al. 2018), whereas the flow pattern polluting rivers and seawater is mercury-carrying water (Bentley and Soebandrio 2017; Kirk et al. 2012). Grand Forest Park in Central Sulawesi was initially affected only in the northern part, including the villages of Layan, Pobo, and Vatu-tela. Now, the southern part of Grand Forest Park has been affected as well, so the contamination of the heavy metal mercury affects not only by people living in Palu City but also those living in Sigi Regency in the buffer zone of Grand Forest Park, including the villages of Pombeve, Petobo, and Ngatabaru. The people in these areas have become restless and worried by the government's lack of regulatory control. So far, the central government and the Central Sulawesi government have issued various regulations banning the use of mercury, including its trading system, but the enforcement of such regulations is weak. This has led to the expansion of traditional gold mining areas affecting all aspects of life (Langston et al. 2015; OCallaghan, 2010). The watershed, as one of the waste disposal areas with trailing processing containing high levels of mercury, has been directly affected by plants using irrigation water, which become contaminated by heavy metals (van der Wulp et al. 2016). The ecological function of Grand Forest Park has been disrupted by reduced land area, triggering drought due to the breakdown of the hydrological cycle (Hansen et al. 2020; Lu et al. 2020; Hartoyo et al. 2021). Besides this, the health of the local community around Tahura is threatened by increasing levels of mercury from the consumption of both contaminated drinking water and agricultural products such as rice, corn, cassava, candlenut, sweet potato, and vegetables. The uncontrolled use of mercury in traditional gold mining activities ultimately causes problems for the environment and public health (Basir-Cyio et al. 2017; Diaz et al. 2020; Rónavári et al. 2021).

We aimed to identify and assess the affected areas as well as the pollution and contamination level in Grand Forest Park in Central Sulawesi, Indonesia on the land and plants.

Materials and methods

Study area and sampling site

The study area of Grand Forest Park includes four subdistricts: Mantikulore, East Palu, South Palu (Palu City area), and Sigi Biromaru (Sigi Regency area), with a total area of 7129 ha. The Grand Forest Park in Central Sulawesi is at an altitude of 200 m above sea level, located between 119°55' and 120°0'0" E and 0°48' and 0°59' S (Abdul Rahman, n.d.; Dinas Kehutanan Sulawesi Tengah 2016). Based on the field conditions identified from aspects of activity spot dispersion and the tendency of traditional gold mining expansion existing in and around Grand Forest Park, the sampling points for land and plants were determined using the perfect zigzag line approach with a very low geomorphological condition diversity assumption (Squire et al. 2020; Moreira Ribeiro Gonçalves et al. 2021). That means the soil characteristic is mostly has a similarity. We chose 20 sampling points, but there were four composited sites those very close to the mine processing areas. Every point in the zigzag line was chosen at a suitable point for research so that the land and plant samples were representative of the local area (Fig. 1).

Soil sampling and preparation

Single soil samples and composite methods were used for soil sampling in the field. A total of 20 samples were collected from the field at 9:00 a.m. according to the method developed (Baillie 2006). The samples were taken at a depth of 2–20 cm from both around the mining areas and in the traditionally cultivated agricultural lands after clearing the litter off the ground. Several soil samples were replicated, but some were composited from sampling points within an average of 1.25 km from Layana (Palu City) to the south of Ngatabaru (Sigi Regency). The samples obtained from 20 core samples in a scientifically determined pattern were mixed thoroughly to mitigate the variability in the field and obtain representative soil samples. The sampling was conducted periodically according to assessment needs. The secondary data involving land and plant samples from 2013 to 2016 served as the basis for trend evaluation and were compared with 2018 data as part of the reevaluation of biophysical changes (land and vegetation morphology conditions). The collected samples were kept in a standard bag to avoid leakage and weight loss and were then transported to the Environment Laboratory in Tadulako University, Palu, Indonesia on the date of sampling. The soil samples were prepared

Fig. 1 Study area in Grand Forest Park in Central Sulawesi, Indonesia. The red point zigzag line is the soil sampling pattern, and the blue point zigzag line is the plants sampling pattern in accordance

with the determination of the sampling points with a low field diversity (Y. Zhang and Hartemink 2017)

through separation of sand, small stones, and other non-soil materials; air drying at room temperature; and oven drying at 105 °C. The air-dried samples were ground up to pass through a 200-mesh sieve. Acid dissolution was conducted according to the 3050B United States Environmental Protection Agency method. Chemicals used included HNO_3 (68%, Sigma-Aldrich), HCl (analytical class $d = 1.18$, 36%, Fisher Scientific), H_2SO_4 (97–98.2%, Sigma Aldrich), HClO_4 (70%, Sigma Aldrich), and H_2O_2 (6% w/v).

Mercury (Hg), copper (Cu), and cadmium (Cd) were measured using cold vapor atomic absorption spectrometry (CV-AAS) to determine the total content in the soil. The results were in line with Ministry of Health Japan standards. We applied several treatments to analyze the soil samples, including the addition of 1 mL of distilled water, 2 mL of $\text{HNO}_3\text{--HClO}_4$, and 5 mL of H_2SO_4 in 500 mg of soil (wet weight) in the flask. The samples were then heated for 30 min at 200–230 °C on a hot plate, and then, Hg was

extracted. After cooling for several minutes, the solution was diluted with distilled water, using up to 50 mL. Only 5 mL of the solution was analyzed using Mercury RA-3 (RA-3, NIC Company). The measurements were repeated three times for each soil sample for accuracy purposes, and then, the results were averaged.

Plant sampling and preparation

The accumulation of mercury, copper, cadmium was analyzed in the plant tissues of corn (*Zea mays* L.), bean (*Phaseolus vulgaris* L.), potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.), srikaya (*Annona squamosa*), candlenut (*Aleuritesmoluccanus*), cassava (*Manihotesculenta*), peanuts (*Arachishypogaea*), and rice (*Oryza sativa*). Plant samples (500 mg) were analyzed using CV-AAS after being cleaned and rinsed several times, dried at 40 °C for 24 h, and finely chopped before laboratory

analysis. The analysis of Hg, Cu, and Cd in plants using the ammonium-acetate extraction method. The plant samples used (10 g) were placed in an oven at 70 °C until the weight was constant, following which they were smoothed and sieved. Subsequently, 0.5 g of the samples was dissolved in HNO₃, H₂SO₄, and 1 M HCl and then ground up and measured. The relationship of Hg, Cu, and Cd concentrations in soil and plants was determined using the transfer factor (TF) = Plant Concentration (Cp)/Soil Concentration (Cs) [TF = Cp/Cs] (Lato et al. 2012; Tura 2018). A TF value ≥ 1 denotes the plant was able to accumulate heavy metals. In contrast, a TF value ≤ 1 indicates the plant was avoidant or does not have bioaccumulating abilities.

Data analysis

The concentration of heavy metals in soil and the contamination of plant tissues were analyzed descriptively and tested using the correlation test (r) of Spearman's rank at a level of significance of 0.05. All data are presented in table and graphic forms using either a bar or line diagram.

Results and discussion

Results

Secondary data

The research data consisted of secondary Hg data sourced from a number of previous research findings around Poboya, whereas the primary data involving Hg, Cu, and Cd covered the entire area of Grand Forest Park from the north of Layana, Palu City to the south of Ngatabaru, Sigi Regency (Basir-Cyio et al. 2017). Compiling the secondary and primary data facilitated the detection of trends in land pollution and plant contamination by heavy metals, including the increase in mining areas. The secondary data of Hg content in soil from 2013 to 2016 are presented in Table 1 and 2. These data were integrated with the primary data obtained in 2018.

Hg concentrations in soil were dominant around the processing areas of gold separation from raw materials, followed by the concentrations found in the settlements and agricultural areas that were closest to the mining areas. The averages total Hg concentrations in soil and plants for the

Table 1 Time series data on Hg concentrations in soil

Sampling Site	2013 *	2014 **	2015 ***	2016 ****	2018
	Level Hg (ppm)	Level Hg (ppm)	Level Hg (ppm)	Level Hg (ppm)	Level Hg (ppm)
	Soil	Soil	Soil	Soil	Soil
Grassland	1.14	0.91	0.65	0.55	0.51
Livestock Area	0.76	0.97	0.45	0.65	0.66
Settlement	0.87	0.45	0.76	0.29	0.27
Gold Processing Area 1	575.16	398.4	400.32	397.4	287.64
Gold Processing Area 2	89.05	83.2	123.65	200.3	189.4
Gold Processing Area 3	84.15	102.3	143.67	123.76	134.8
Gold Processing Area 4	235.53	200.4	200.35	187.32	176.8
Gold Processing Area 5	370.73	300.67	198.34	234.98	188.7

Table 2 Time series data on Hg concentrations in soil and plant tissues

Sampling Site	Level Hg (ppm)		Level Hg (ppm)		Level Hg (ppm)		Level Hg (ppm)	
	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant
Maize cropping	1.45	0.23	1.23	0.38	0.69	0.21	0.43	0.11
Paddy area	0.99	0.26	0.76	0.24	0.21	0.12	0.49	0.17
Coconut plantation	0.57	0.12	0.65	0.08	0.43	0.12	0.56	0.25
Peanut cropping	0.54	0.18	0.33	0.11	0.65	0.28	0.21	0.07
Cassava cropping	1.65	0.76	0.45	0.19	1.23	0.32	0.32	0.03
Cocoa plantation	0.76	0.33	0.32	0.11	0.54	0.17	0.19	0.02
Onion cropping	1.24	0.43	0.87	0.16	1.23	0.08	0.34	0.13

Data source: Compilation. * (Mirdat 2013), **/*** (Isrun 2015), **** (Mega M. Sari et al. 2016; Nakazawa et al. 2016)

Fig. 2 Average Hg concentrations in 2013–2016 at various sampling sites

2013–2016 period are presented in Fig. 2. The compiled data show that the TF values of Hg were in the following decreasing order: peanut cropping > cassava cropping = cocoa plantation > rice area > coconut > maize cropping > onion cropping.

Hg concentrations from 2013 to 2016 were highest in grassland (3.25 ppm), followed by livestock (2.83 ppm) and settlement areas (2.37 ppm) (Fig. 3a). Based on the data in Table 1, the Hg concentrations around the mine processing areas were very high for all sampling points from 2013 to 2016. Even in 2013, the highest Hg concentration occurred at Gold Processing Area 1 at 575.16 ppm. The data for all processing areas are shown in Fig. 3b.

The accumulation of Hg at the mine processing sampling points was correlated with the amount of mercury used in the separation process of gold from raw materials and with concentrations in plant tissues. Hg concentrations in grassland, livestock, and settlement areas were generally less than 1.0 ppm except for grassland in 2013, which was

above 1.0 ppm, but gradually decreased in 2016 (Fig. 3a). The results of the Spearman's rank correlation test between Hg concentrations in soil and plant tissues were significant with $r=0.75$ and $\rho=0.026$ being smaller than $\alpha 0.05$ ($\rho=0.026 < 0.05$) at the 95% confidence level.

Primary data

Primary data, obtained in 2018 (January–February) and used as time series data for 2013 to 2016, were taken from wider sampling sites, ranging from the north to the south in accordance with the stretch of Grand Forest Park in Central Sulawesi. The concentrations of Cu, Cd, and Hg from three subareas of the sampling sites including (1) inside the Grand Forest Park area Tahura (THR), (2) Ngatabaru (NBR), and (3) Poboya (PBY) are presented in Table 3, 4, and 5, respectively.

Fig. 3 Hg concentrations in **a** three sampling sites and **b** five processing areas in the north and west of Grand Forest Park

Table 3 Hg, Cu, and Cd concentrations in soil and plant tissues in the Grand Forest Park area (THR)

Code of Sampling Site	Copper (Cu) (ppm)	Transfer Factor (TF)	Cadmium (Cd) (ppm)	TF	Mercury (Hg) (ppm)	TF
THR 1 Soil	22.48		13.74		0.29	
THR 4 Soil	27.35		11.19		0.24	
THR 5 Soil	1.25		14.34		0.21	
THR 7 Soil	1.50		8.10		0.21	
THR 1 Srikaya Leaf	0.54	0.02	2.35	0.17	0.14	0.48
THR 4 Candlenut Leaf	0.50	0.02	3.60	0.32	0.12	0.50
THR 5 Candlenut Leaf	0.30	0.24	3.59	0.25	0.14	0.67
THR 7 Mango Leaf	0.10	0.07	2.37	0.29	0.12	0.57

Table 4 Hg, Cu, and Cd concentrations in soil and plant tissues in Ngatabaru (NBR)

Code of Sampling Site	Copper (Cu) (ppm)	TF	Cadmium (Cd) (ppm)	TF	Mercury (Hg) (ppm)	TF
NBR 1 Soil	1.74		10.58		0.60	
NBR 3 Soil	2.25		13.12		0.79	
NBR 5 Soil	3.99		6.23		0.65	
NBR 1 Cassava	0.34	0.19	0.49	0.05	0.29	0.48
NBR 3 Sweet Potato	0.55	0.24	0.62	0.05	0.35	0.44
NBR 5 Sweet Potato	0.45	0.11	0.37	0.06	0.33	0.51

Table 5 Hg, Cu, and Cd concentrations in soil and plant tissues in Poboya (PBY)

Code of Sampling Site	Copper (Cu) (ppm)	TF	Cadmium (Cd) (ppm)	TF	Mercury (Hg) (ppm)	TF
PBY 1 Soil	3.49		4.99		0.43	
PBY 2 Soil	2.25		1.87		0.55	
PBY 3 Soil	1.50		0.24		0.53	
PBY 1 Peanuts	0.15	0.04	0.14	0.03	0.42	0.98
PBY 2 Paddy	1.09	0.48	0.14	0.07	0.46	0.84
PBY 3 Cassava	0.35	0.23	0.13	0.54	0.31	0.58

Fig. 4 Cu, Cd, and Hg concentrations in the Grand Forest Park area in Central Sulawesi

The results of the observations show that Cu and Cd contents were higher than that of Hg both in the soil and plant tissues in the Grand Forest Park area (Fig. 4).

The concentrations of Cu and Cd were much higher than that of Hg in the Grand Forest Park area. The highest Cu

concentrations in the sampling sites were recorded at THR-4 (27.35 ppm) and THR-1 (22.48 ppm). The highest Cd concentrations in soil were recorded at THR-5 (14.34 ppm), THR-1 (13.74), and THR-4 (11.19 ppm), whereas the highest Hg concentrations were recorded at THR-1 (0.29 ppm)

and THR-5 (0.24 ppm). The trend in the concentrations of Cd, Cu, and Hg in the Ngatabaru sampling sites (NBR) was relatively the same as in the Grand Forest Park sampling sites (Fig. 5). The highest Cd concentrations were recorded at NBR-3 (13.12 ppm) and NBR-1 (10.58 ppm) (Fig. 5a). The highest Cu concentrations were recorded at NBR-5 (3.99 ppm) and NBR-3 (2.25 ppm) (Fig. 5b). The highest Hg concentrations were recorded at NBR-3 (0.79 ppm) and NBR-5 (0.65 ppm) (Fig. 5c).

The concentration of heavy metals in the plant tissues was used as an indicator to determine the TF of each sampling site. The TF values of Cu at the Tahura, Ngatabaru, and Poboya sampling sites were 0.09, 0.18, and 0.25, respectively. The TF values of Cd were 0.26, 0.05, and 0.20, whereas those of Hg were 0.55, 0.47, and 0.80 in the Tahura, Ngatabaru, and Poboya sampling sites, respectively.

Fig. 5 a Cd, b Cu, and c Hg concentrations in soil and plant tissues at the Ngatabaru sampling sites

The results of the analysis of Cu, Cd, and Hg concentrations in the Poboya (PBY) sampling sites are presented in Fig. 6.

Based on the standard error values of Cu, Cd, and Hg at subsampling sites PBY-1, PBY-2, and PBY-3, we found significant differences. The Cu and Cd concentrations at PBY-1 and PBY-2 were higher than these at PBY-3, whereas Hg concentrations were higher at PBY-2 (0.55 ppm) than at PBY-1 (0.43 ppm) and PBY-3 (0.53 ppm), although the difference between PBY-2 and PBY-3 was not significant. The results of the Spearman's rank correlation test of the average of the concentrations in soil and plant tissue for Cu showed that the obtained r was 0.52 with $\rho=0.13$. The correlation was not significant ($\rho 0.13 > 0.05$). The obtained r values for Cd and Hg were 0.88 and 0.86, respectively. Both metals had a significant correlation between concentrations in soil and plant tissues (both $\rho 0.001 < 0.05$). Specifically, the TF values at the THR, NBR, and PBY sampling sites from different types of plants can be presented as follows: (1) the TF values for Cu at the THR sampling site were in the decreasing order of candlenut > mango > srikaya; for Cd, they were mango > candlenut > srikaya; and for Hg, they were candlenut > mango > srikaya. (2) The TF values for Cu at the NBR sampling site were cassava > sweet potato; for Cd, they were sweet potato > cassava; and for Hg, they were cassava > sweet potato. (iii) The TF values for Cu at the PBY sampling site were paddy > cassava > peanut; for Cd, they were cassava > paddy > peanut; and for Hg, they were peanut > paddy > cassava.

Translocation, or the transfer of heavy metals dissolved in the soil, is determined by chemical reactions (pH) of the soil solution and is affected by the soil's physical properties (Aliku and Oshunsanya 2018; Lipiec and Usowicz 2018). In general, the study areas in Grand Forest Park, Ngatabaru,

Fig. 6 Copper, Cadmium, and Mercury concentrations in soil and plant tissues at the Poboya sampling sites

and Poboya had relatively similar organic materials, volume density, porosity, and soil texture. This was due to the same materials being formed through the alluviation process, which formed an alluvial soil.

Discussion

Cu and Cd

The highest concentrations of Cu were recorded at Grand Forest Park (THR-4: 27.35 ppm and THR-1: 22.48 ppm), followed by Ngatabaru (NBR-5: 3.99 ppm and NBR-3: 2.25 ppm), whereas the Cu concentrations at Poboya ranged from 1.50 to 3.50 ppm. In general, the Cu concentration in soil ranged from 1.00 to 50 ppm (Fedje and Strömwall 2016; Gonzaga et al. 2018; Pedersen et al. 2018). However, it can reach 200 ppm depending on the source of pollution (Patrona et al. 2018; Vergeer et al. 2018). Accordingly, the Cu concentrations in the study areas were still in the low range, at less than 25 ppm (Ferraro et al. 2015; Li et al. 2016; Vance et al. 2016). The balance in the Cu concentration in soil and plant tissues was assumed to be the same and be positively correlated (Ferraro et al. 2015; Li et al. 2016; Vance et al. 2016). The higher the Cu concentrations in a soil solution, the higher the Cu concentrations in the plant tissues, even though each plant species has different accumulation and avoidance characteristics (Liang et al. 2018; Puschenreiter et al. 2017; Qiutong and Mingkui 2017) indicated by the TF value. The TF value indicates whether a plant species is a bioaccumulator or rejects heavy metals entering its tissues. The TF values at THR, NBR, and PBY were 0.09, 0.18, and 0.25, respectively; these three values were all < 1.0 , meaning that the sample plant species in the three sites are not bioaccumulators of Cu. However, rice at Poboya had a higher accumulation ability than cassava and peanut at 0.25 ppm.

The ability of rice to accumulate Cu is dangerous because it is one of the staple foods of Indonesian people, especially those in Central Sulawesi. The stronger the ability of the crops to accumulate heavy metals, the greater the threat to human health (da Rosa Couto et al. 2018; Mustafa and Komatsu 2016). The highest Cd concentrations in soil in the Grand Forest Park area were recorded at THR-5 (14.34 ppm), THR-1 (13.74), and THR-4 (11.19 ppm), whereas in the Ngatabaru area, these were recorded at NBR-3 (13.12 ppm) and NBR-1 (10.58 ppm). These data indicate that the dispersion of Cd in both soil and plants was relatively even from the northern part of Grand Forest Park to its southern part, predominantly in the crop agricultural areas. The Cd accumulation in the soil solution was correlated with the accumulation in plant tissues (Yu et al. 2018), which was positive with an r value of 0.88, which was statistically significant. The Cd concentrations in Grand Forest Park, Ngatabaru, and Poboya

were high (> 7 ppm) and posing a potential threat to public health if they accumulate in the crops consumed (Langston et al. 2015; Zhao-Fleming et al. 2017). The Cd concentrations in the sample plants from Grand Forest Park ranged from 0.17 to 0.32 ppm, those from Ngatabaru were in the range of 0.05 to 0.06 ppm, and from Poboya were in the range of 0.03 to 0.54 ppm. These ranges are still within the low-to-medium threshold (< 0.8 ppm) (Song et al. 2015). The Cd concentrations in plants were low-to-medium even though those in soil were high because the indicator plants mango, candle-nut, srikaya, cassava, and rice sampled from Grand Forest Park, Ngatabaru, and Poboya have avoidance abilities; thus, they are not bioaccumulators (Song et al. 2015; Tack 2017; Wu et al. 2018). During the avoidance process, plant roots respond each time they absorb Cd from solution (He et al. 2017; Jafari et al. 2018; Koike et al. 2017). The plants have the ability to prevent the entry of Cd through their cellular system (Millaleo et al. 2010) and use organic acid secretion in their root environment to chelate heavy metals (Dong et al. 2007; Potters et al. 2009; Yang et al. 2000) and change their root architecture (Potters et al. 2009; Remans et al. 2012).

The characteristics of each plant differ in response to the presence of Cd content in their root system (Yang et al. 2017). The presence of Cu and Cd in concentrations exceeding the tolerable threshold in plants may lead to oxidative stress (Chen et al. 2018; Etesami 2018; Nowicka et al. 2016). Plants experiencing oxidative stress due to heavy metal concentration can be improved by the presence of the hormone group brassinosteroids (BRs), as phytohormones regulate the growth and development of various plant species (Banik et al. 2018; Sahay and Gupta 2017) as well as promote high biological activity. When plants experience stress, BRs perform protective activities against the anthropogenic effects of various human activities (Etesami and Maheshwari 2018; He et al. 2018). The existence of BRs in plants with oxidative stress can inhibit lipid degradation resulting from the overproduction of reactive oxygen species (ROS) under stress conditions and increase antioxidant activity (Shahzad et al. 2018; Stolpe et al. 2017). BRs also have the ability to promote phytochelatin synthesis (Argyaki et al. 2018; Maar et al. 2018). The European Union considers Cd as requiring the most attention because it has become a global issue as a result of its environmental effects (Abraham et al. 2018; Yin et al. 2016; Zhang et al. 2016).

Hg

The Hg concentrations in soil in the study areas began to increase in the south after the traditional gold mining activities expanded, focused not only in Poboya (Palu City) but also entering the Ngatabaru area (Sigi Regency). In the processing areas, PBY-1 and PBY-5 showed concentrations above 250 ppm. In 2013, Hg concentrations in the processing areas reached 575.15 ppm, and in 2018, the concentrations

decreased to 287.64 (49.98%). Although the Hg concentrations in soil have decreased in the Poboya sampling site, their impact will be widespread due to the expansion of the mining area, resulting in increased environmental effects (Abraham et al. 2018; Zhang et al. 2016). These effects have become a threat to agricultural areas and settlements south of Palu City, which were previously been classified as safe. The larger number of miners and wider areas is correlated with the need for mercury use (Protano and Nannoni 2018; Wu et al. 2014; Yin et al. 2016). Strict government regulation is required to ensure that mercury's effects on the environment and human safety can be minimized (Aaseth et al. 2018; Yin et al. 2010). A number of indicator plants whose Hg contents were analyzed showed Hg accumulation in the plant tissues, including sweet potato, cassava, rice, and peanut. The average concentration at Poboya reached 0.39 ppm and 0.32 ppm at Ngatabaru. The increasing trend of Hg accumulation in Ngatabaru means that the impacts of anthropogenic activities have been widespread. Humans have played a substantial role in the acceleration, expansion, and worsening of environmental pollution and contamination in soil and plants (Singh et al. 2018; Sushkova et al. 2018). Although mercury is released in metal or ionic form, it is readily methylated by bacteria in certain environments resulting in methyl mercury, a highly toxic organomercurial compound (Protano and Nannoni 2018; Yin et al. 2010).

Methyl mercury toxicity is magnified in organisms in higher tropic levels due to its high accumulation in plant tissues (Oswald and Carey 2016; Shepherd et al. 2018). Organomercurial compounds are readily absorbed and can act as neurotoxins. More than 90% of methyl mercury is absorbed into the bloodstream through the gastrointestinal tract. In comparison, this absorption rate is less than 10% for mercury salts and only 0.1% for mercury (Abbas et al. 2017; Jadán-Piedra et al. 2018). Hg accumulates in the plant tissues of fruits, vegetables, and other foodstuffs, especially peanut, sweet potato, and rice, which are intermediary foodstuffs that easily move Hg from the soil environment into the human body (Chamba et al. 2017; Wang et al. 2017). Hg accumulation could be determined from the average TF values in the THR, NBR, and PBY sampling sites, which were much higher than these of Cu and Cd ($Hg > Cd = Cu$, or $0.61 > 0.17 = 0.17$). The higher the TF value of a plant, the more it functions as a bioaccumulator (Stratópoulos 2018; Sushkova et al. 2018).

Chemical reactions in the soil solutions of Cu, Cd, and Hg are also influenced by the soil's physical properties (Chen et al. 2018; Maar et al. 2018; Yang et al. 2017). In general, the study areas in Grand Forest Park, Ngatabaru, and Poboya had relatively similar organic materials, volume density, porosity, and soil texture because the same materials were produced through the alluviation process, encouraging the formation of alluvial soils (Singh et al. 2018; Sushkova et al. 2018; Yin et al. 2016).

Conclusion

The concentrations of Cu, Cd, and Hg in and around Grand Forest Park were surveyed, and the data from three sampling sites—Grand Forest Park, Ngatabaru, and Poboya—were obtained both from the land and plant tissues. The highest Hg concentrations were recorded around the processing areas followed by the locations closest to settlements and agricultural areas. The traditional gold mining areas have expanded from Poboya (Palu City) to the south of Grand Forest Park including Ngatabaru (Sigi Regency). The selected indicator plants were cassava, sweet potato, peanuts, corn, rice, candlenut, mango, and srikaya. All the sampling sites were found to be contaminated with heavy metals followed by increased concentrations in plant tissues. The dispersion of Cu, Cd, and Hg both in soil and plants was relatively even from the northern part of Grand Forest Park to its southern part, predominantly in the crop agricultural area. The Cd concentrations in Grand Forest Park, Ngatabaru, and Poboya were high (> 7 ppm). Hg accumulation was gauged using the average TF values in the THR, NBR, and PBY sampling sites, which were much higher than these of Cu and Cd ($Hg > Cd = Cu$, or $0.61 > 0.17 = 0.17$). Proper law enforcement is required to prevent the expansion of illegal traditional gold mining areas for the sake of environmental safety and community protection against health problems caused by the consumption of agricultural products contaminated by heavy metals. The relocation of residents who living around the mine area is one of the safest ways for the communities. In addition, using methods that are more environmentally friendly, namely the water method is the best choice without using mercury. However, to use environmentally friendly technology, government regulations and socialization intensively are needed for the communities to be able to consider the negatives caused by using mercury.

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Declarations

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