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Review

ASGM status in West Nusa Tenggara Province, Indonesia

Baiq Dewi Krisnayanti*

International Research Centre for Management of Degraded and Mining Lands, Brawijaya University, Jl.Veteran 1 Malang 65145, Indonesia

*bdewi.krisnayanti@gmail.com

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Abstract: Artisanal Small-Scale Gold Mining (ASGM) obviously contributes to serious environmental and health issue for miners, nearby populations, and larger community when the use of mercury (Hg) occurs. Mercury amalgamation is used as a gold recovery technique by 10-12 million ASGM miners around the world and a predicted around 1000 tonnes of mercury are discharged into the environment every year as a result of poor mining practices. Exposure to mercury can cause serious health effects for future generation, and miners and their families are vulnarable group to expose with mercury vapor and methyl mercury contaminated food in ASGM areas, resulting in increase of levels of mercury in human specimens. Thus, investigating the the effects of mercury on the environment and people health are urgently necessary for developing a better solution to eliminate further mercury contamination to environment in West Nusa Tenggara (WNT) Province. A field survey had been conducted for this research in two main ASGM spots in WNT Province: Sekotong-Lombok island and Taliwang-Sumbawa island. As part of the study, an initial health survey and socio-economic of workers/miners was conducted. Volunteer participants at sampling locations across Sekotong-Lombok and Taliwang-Sumbawa (exposed; indirect exposed; non exposed groups) answered a questionnaire, and allowed the sampling of hair for subsequent analysis. The ore, tailing, plants and soil samples were also collected for investigating Hg concentration on the substances. The results found that the impact of ASGM on increasing economic activity leading to jobs, income and opportunities for social development is positive. However, there is risk of contamination in soil and plants environment through mining activity and high Hg concentration discovered in human body in a short time of ASGM activity. The environmental sustainability of mining can be better regulated within legalised areas. Environmental monitoring will define unacceptable risk and allow for advanced implementation of remedial measures before an uncontrollable disaster occurs.

***Keywords**: ASGM, mercury, West Nusa Tenggara*

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Introduction

The term artisanal and small-scale gold mining (ASGM) loosely describes any informal mining practice. Artisanal and small-scale gold mining is practiced by an estimated 10-15 million people in 70 countries and various statistics place ASGM as responsible for 15-20% of global gold production. ASGM is associated worldwide with social and environmental degradation; however the economic activity created by mining is a key stimulus for development in poor rural areas. Indonesia has a regulated large-scale gold-mining sector, and an extensive artisanal gold-mining sector, but no formal small-scale mining sector. Artisanal gold mining in Indonesia is illegal and operates in a vacuum of health and environmental safety protocols. In 2010, Indonesia produced 127 tonnes of gold. Assuming 15-20% of this gold was produced by ASGM, the Indonesian artisanal gold-mining sector could be contributing in the order of 20 tonnes of gold per annum. Historical records suggest that artisanal gold mining has been practised throughout Indonesia for hundreds if not thousands of years. However, the scale of operation has steadily increased since 2000 (INCAM, 2013).

Concern about mercury (Hg) toxicity as global issue, the European Union Commission and WHO have stated that even very low concentrations of Hg may be could affect human health (EC, 2006; WHO, 2009) and its recommended to reduce or eliminate the mercury use in any aspect (Holmes et al., 2009). Mercury is a global pollutant and its transport and deposition presents serious risks to the environmental. Recognising this problem, over 130 countries have signed the United Nation's Minamata Convention as an agreement to reduce the emission and use of Hg (UNEP, 2013; Xu et al, 2015). The greatest remaining use of Hg worldwide is for gold recovery in informal and unregulated mining operations.

Mercury amalgamation is used as a gold recovery technique by 10-12 million ASGM miners around the world (Velásquez-López et al., 2011), and an estimated 1000 tonnes of mercury are released into the environment annually as a result of poor mining practices (Velásquez-López et al., 2011). This represents approximately 38% of global mercury emissions (Xu, et al, 2015) and contributes to serious environmental and health issues for miners, nearby populations, and larger communities (WHO, 2009). ASGM is practised in West Nusa Tenggara Province (WNT) began in mid 2009 at the Sekotong region of Lombok Island, and in 2010 spread out to the next island which is Sumbawa Island. Miners fill sacks with rock dug from simple mine shafts, The rock is crushed by hand, and then pulverized using simple rod mills. Liquid mercury is added during the final stages of grinding for amalgamation. The mercury-gold amalgam is separated from the waste rock (tailings), before the waste is disposed of to land or water, or further processes to cyanidation plants. A final cyanide leach of the amalgamation tailings will recover more gold, before the cyanidation tailings are disposedof, again to land or water (riverbanks and sea). The gold product recovered at each step is sold to the local market.

The use and cycling of mercury at some ASGM locations has been extensively studied, in particular in Brazil (Veiga, and Meech, 1995;Veiga et al., 1995). Metcalf and Veiga (2012) suggested two thirds of the total 25 tonnes of mercury used per annum in artisanal mining in Zimbabwe is lost to tailings. The use of Hg during the refining of gold results in the volatilization of an estimated 300 tonnes of Hg directly to the atmosphere annually, and 700 tonnes are discharged via mine tailings into air, soil, and rivers, and lake (Spiegel and Veiga, 2010). Telmer and Stapper (2007) explained mercury use in a different context and noted that in a whole ore amalgamation process in Indonesia for every 20 gram of mercury consumed to produce 1 gram of gold (19 gram of mercury is lost to tailings and 1 gram to the atmosphere). Worldwide this may lead to the annual release up to 1,000 tonnes of Hg to the environment. Between 100 and 150 tonnes per year are estimated to be released from Indonesia (Veiga et al., 2006). Thus, describing the the status of mercury on the environment and people health are urgently necessary for developing a better solution to eliminate further mercury contamination to environment in West Nusa Tenggara Province.

ASGM status in Indonesia

Balifokus (2017) stated that in November 2015, Director General of Indonesian Custom, Ministry of Finance, aborted the exportation of 80 containers containing illegal mineral, including cinnabar ore, valued approximately IDR 73.8 billion which would be sent to the Netherlands, Taiwan, Korea, Hong Kong, India, Singapore and Thailand. Indonesia has several potential cinnabar mining sites, which are spread out in Central Kalimantan, Southeast Sulawesi, and Seram islands. The processing of cinnabar ore becoming liquid Hg in Indonesia mostly taking place in Java, it is in Sukabumi, Bekasi and East Java areas and then distributed to ASGM in Indonesia. Furthermore, the Indonesian Community Miners Association claimed that about 1 million of the association members, use mercury to extract gold about 3500 tonnes per year. For example, In one of the ASGM hotspots in West Nusa Tenggara province, Sekotong and Pelangan areas, at least about 30 metric tonnes of mercury distributed per week to serve about 10,000 ball-mills at the price of IDR 1,5 million per kg.

Male et al. (2013) stated that a significant proportion of mercury is lost to the tailings produced on Buru Island. The lowest concentration of total recoverable mercury found in sediments from trommol waste ponds was 682 mg/kg. In comparation, the mercury concentrations in muds of Minimata Bay, where the notoriust mercury pollution incident occurred showed the levels ranging from 19 to 908 mg/kg (Fujiki and Tajima, 1992). Sediments from river and bay sites on Buru Island have a higher proportion of available mercury than elemental mercury and more strongly bound mercuric sulfide compared to that of trommol waste, it suggests a rapid uptake of mercury use in ore processing since 2011.

Telmer et al. (2007) investigated that the typical amalgamation practice in the gold fields around Kareng Pangi, Kalimantan was to use 300 grams of mercury (range: 250-400) to make an amalgam weighing 20 grams containing 10 grams of gold. Mercury recovered is 287 grams and so about 3 grams or 30% is lost to the tailings while the remainder is contained in the amalgam. The amalgam produced here was typically 50% Hg by weight. The mercury lost to the tailings is lost in the form of flowered mercury (microspherules) and is lost due to adsorption to mineral surfaces, particularly to oxides like limonite.In additon, since 1989, ASM has emitted to the atmosphere in the Kareng Pangi region 30 tonnes of mercury where most it directly into the middle of the town of Kareng Pangi and at least 13 tonnes has been lost to tailings.

Tomiyasu et al. (2013) analyzed soil Total Hg (THg) at four locations around ASGM operations in West Java, Indonesia, and found average THg concentrations of 13.5, 4.29, 1.93 and 55.6 mg/kg, respectively. These levels are above the Chinese National food safety standard for Hg in agriculture soil (1.5 mg/kg).They predicted that dissolved or suspended mercury was transported to soil through irrigation channels. The Hg concentrations in the sediments collected from fish farms around mining sites were as high as 133 mg/kg.

Bose-O'Reilly et al. (2010) found that the whole community at ASGM areas in Central Kalimantan and Sulawesi, Indonesia were exposed to mercury as indicated by elevated mercury levels in the urine, blood and hair. ASGM in Kalimantan has operated since 17th century, however the increasing gold price in the first decade of the 21st Century say an expansion of ASGM to other islands, including Lombok and Sumbawa Islands. Artisanal miners can be critically exposed to mercury, either through direct handling of the metal, or by inhaling the mercury vapors generated during the burning of the gold-mercury amalgam. In many cases, the gold heat separation processes is performed mostly in locations close to family or community members, resulting exposing other people to increase levels of gaseous mercury, while the most important and dangerous pathway of exposure to metallic mercury for artisanal gold miners and their families is through Hg vapor inhalation (WHO, 2009).

Nakazawa et al. (2016), indicated that the community of Palu city, Central Sulawesi was at serious risk from exposure to high concentrations of atmospheric Hg(0). The average day time point-sample Hg(0) concentrations in the city ranged from 2,096 to 3,299 nanogram/m^3, as measured with a hand held mercury analyzer over 3 days in July 2011 and the average daytime Hg(0) concentration in the Poboya gold-processing area was 12,782 nanogram/m^3, which all concentrations were substantially higher than the World Health Organization air-quality guideline for annual average Hg exposure (1000 nanogram/m^3).The results indicated that 93% of the sample population overall was at risk of mercury toxicity, that could lead the damage to the central nervous system due to chronic exposure. In additon, Ismawati et al. (2015) measured the mercury vapour in Pongkor, West Java, about 15 m from the active ball-mills unit showed the maximum value of 50,380 nanogram/m^3, far exceeding the threshold value and safe reference set by the WHO that is <1,000 nanogram/m^3. The average mercury vapour concentration in the village was 4,150 nanogram/m^3.

Gaseous elemental mercury (Hg0) is very stable with a residence time between 0.5 and 2 years and Hg deposited in rice paddies can be readily transformed into the more toxic organic species, methylmercury (MeHg) (Li et al., 2011). The burden of mercury toxicity to ASGM communities is compounded by the bioaccumulation of Hg in food (Holmes et al., 2009, Shao et al., 2013). Meng et al. (2011) and Li et al. (2010) discovered elevated MeHg in rice grown around tailings contaminated Hg is more 10-100 times higher than other locally grown plantation. Shao et al. (2013) stated that MeHg can accumulate in hair during growth (1 cm per month), and hair MeHg concentration can possibly reflect longer-term MeHg exposure. In addition, most of the previous studies reported that MeHg constituted 80% of THg in hair and the major exposure route was through fish consumption (Molina et al., 2015). Ismawati et al. (2015) measured the THg of rice concentrations from ASGM area in Pongkor, West Java with a portable Hg vapour analyser (Lumex, Model RA-915+/PYRO-915+, St. Petersburg, Russia) and found that the average of THg in rice was 143 ppb with the minimum and maximum value were 101 and 200 ppb, while the Indonesian's tolerable limit as set by the Decree of the Directorate General of Food and Drugs Surveillance of Indonesia No. 03725/B/SK/VII/89 dan SNI 01-2729.1-2006 is 50 ppb. Kambey et al. (2001) analysed that the whole fish tissue levels sampled from a region of illegal mining in North Sulawesi Minahasa Peninsula that heavily impacted by illegal mining activities contained significant amounts of mercury which were four times the levels recommended by the World Health Organization for consumption restrictions.

Due to a highly toxic metal, mercury is directly affect the nervous and cardiovascular system. Over a short period time of high doses mercury:nausea, vomiting, diarrhea and severe kidney damage are may occur. In addition, nerve damage, hallucinations, the inability to concentrate and memory loss, tremors, loss of dermal sensitivity, and slurred speech can also arise (Nierenberg et al., 1998; Mohapatra et al., 2007; Bose-O'Reilly et al., 2010). Furthermore, Bose-O'Reilly et al. (2016) found that 15 out of 18 examined individuals miners in Cisitu, West Java were in toxicated, it is showing both the typical mercury-related symptoms such as ataxia, tremor and coordination problems, as well as having elevated levels of mercury in the urine and hair samples. From the hair analyses, the examined miners exceeded the alert level of 1 mg/g, and five of them with Hg concentrations above the action level of 5 mg/g with a maximum of 25 mg/g.

Mercury use

Rocks containing gold crushed into 1-2 cm then processed through the amalgamation process using *gelondong* with length 55-60 cm and a diameter of 30 cm with a 3-5 iron rod inside the *gelondong* as a grinder. The processing of gold amalgamation conducted by mixing the ore with mercury to form the amalgam (metal alloy Au - Hg) with a water medium. Each *gelondong* can accommodate 2-3 kg of gold ore, then running for 3-4 hours. At every run, around 250-500 grams of Hg added onto the *gelondong* for the amalgamation process. Once the round is completed (4 hours), estimated the rocks have become fine sand grain size of less than 0.5 mm, then the water is sprayed into the *gelondong*, forming a sludge which is collected on tailing pond and the amalgam (Au-Hg) is collected onto the small bucket. The amalgam is then placed to the filter cloth, squeezed until most of the mercury out passes the filter cloth. Furthermore, the gold is separated with burning process (evaporation of mercury) at a temperature of 400^{o}C to obtain the gold and usualy is done in open place. The rest of the tailings is quite often discharging to the area around the mine site including agricultural land. The rest of mercury from the amalgamation process which passes through the filter cloth always reuse in subsequent amalgamation process. In 2011, the number of trommols around Lantung village, Sumbawa and nearby villages were 10.040 trommols. Calculating the use of mercury in this area by 250 gram resulted 2.5 tonnes per day. Meanwhile, in 2009, there were 1268 trommols, and in 2011 the numbers of trommols in Sekotong district were 4630, and 140 of cyanidation tanks. It is estimated the mercury use in 2011 for this region was 1.15 ton per day. Furthermore, at Pringgarata district in 2011, there were 1420 trommols dan 127 cyanidation tanks, it is predicted 0.5 ton of mercury/day use in this area. Pringgarata district was only the site for gold processing, while the gold ore came from different areas such as Sumbawa and Sekotong. In 2012, CBES calculated that the number of amalgamation cylinders in West Sumbawa Regency were 5000 cylinders and miners used an average of 250-500 grams of mercury/cylinder. Therefore, it is estimated that the amount of mercury use in West Sumbawa Regency alone was more than 1.25 tonnes per day (Krisnayanti et al. 2016).

The impact on environment and human

Krisnayanti et al. (2012) discovered that across the ASGM areas of Lombok and Sumbawa: ASGM occurs alongside farming, and the agriculture sector is dominated by rice production. At many locations, rice paddies can be seen directly adjacent to amalgamation or cyanidation operations and cyanidation waste is discharged directly into rice paddies which have been informally re-designated as tailings ponds. These ponds was not designated for proper leachate containment, and therefore soluble complexed mercury, including mercury cyanide, is free to set in the environment. The tailings sampled all exceeded the maximum permissible concentration for mercury in soil set by the Indonesian Government (20 mg/kg). The average mercury concentration in amalgamation and cyanide tailings collected from Sumbawa was very similar to the concentration recorded from Lombok (Tables 1 and 2).

Tabel 1. Total Hg concentration on amalgamation tailing at Tingkik and Lape districts, Sumbawa in 2011.

No	Location	THg (ppm)
1	Tingkik	3958.04
2	Tingkik	4587.41
3	Tingkik	1020.98
4	Lape	2699.30
5	Lape	3538.46
6	Lape	811.19
7	Lape	1790.21
8	Lape	3608.39
9	Lape	1860.14

Table 2. Total Hg concentration on tailing at Sekotong district, Lombok in 2011.

No	Location	Tailing	THg (ppm)
1	CandikManis	Cyanidation	1004.29
2	CandikManis	Cyanidation	1465.66
3	Medang	Cyanidation	1444.20
4	Medang	Cyanidation	1272.03
5	Gili Genting	Cyanidation	1669.52
6	Gili Genting	Cyanidation	1379.83
7	Elak Juring	Amalgamation	4657.34
8	Elak Juring	Amalgamation	1510.49
9	Medang	Amalgamation	7454.55
10	Tembowong	Amalgamation	4307.69
11	Tembowong	Amalgamation	3118.88
12	Tembowong	Amalgamation	111.89
13	Tembowong	Amalgamation	741.26
14	Tembowong	Amalgamation	7874.13
15	Lb. Poh	Amalgamation	881.12
16	Lb. Poh	Amalgamation	2349.65
17	Lb. Poh	Amalgamation	391.61
18	Gn. Ketapang	Amalgamation	6615.38
19	Gn. Ketapang	Amalgamation	2699.30
20	Medang	Amalgamation	8363.64

From the amalgamation tailing samples that were collected in 2011 from Lantung areas showed the total Hg concentration on tailing was very high which were 1165.05, 3855.85 and 1881.95 ppm. In the nearby Lantung villages, the total Hg concentration was also very high which were 1575.36 and 2756.30 ppm, and the highest concentration found was 7374.66 ppm. In addition, the total Hg concentration on amalgamation and cyanidation tailing from Pringgarata area in 2011 showed the result was relatively high, however no sign of Hg accumulation occured in the river (Table 3).

Table 3. Total Hg concentration on amalgamation and cyanidation tailing at Pringgarata district, Lombok in 2011.

No	Location	Tailing	THg (ppm)
1	Bagu	Amalgamation	374.89
2	Sintung	Amalgamation	382.35
3	Pringgarata	Amalgamation	692.35
4	Sintung	Amalgamation	266.06
5	Bagu	Cyanidation	272.99
6	Marbaya	Cyanidation	454.58
7	Sintung	Cyanidation	203.76
8	Barejulat	River sediment	8.99
9	Bagu	River sediment	3.48
10	Jagaraga	River sediment	4.39

The results indicated that in the early gold rush, the gold processing that have been doing by Lombok and Sumbawa's miners were not efficient nor effectivy, due to most of the mercury use loss into tailings. This is due to the Lombok and Sumbawa´s miners were new to mining activity while their daily occupation are farmer and fisherman, thus there was not enough knowledge and experiences regarding the use of mercury in gold processing. Most common knowledge was the more mercury used the more gold recovered. Krisnayanti et al. (2012) who analyzed the samples of paddy rice grain collected adjacent to cyanidation tailings ponds showed that methylmercury concentrations was greater than 100 ng/g. This is five times above the Chinese permissible level for total mercury in food crops. Furthermore, the mean total mercury concentration in hair of Lombok ASGM workers was greater than that in a non-exposed population.

Mining in Lombok began in mid-2009 however by 2012, 70% of miners had been exposed by mercury (Hg) as indicated by a total Hg (THg) in miner's hair above the permitted level of 1 µg/g set by the WHO. This indicates the primary pathway of mercury exposure is inhalation of volatile mercury in the atmosphere occured. Current-day exposure appears to be the inhalation of volatile mercury from the atmosphere rather than the consumption of methyl-mercury-contaminated food (rice and fish), although the relative importance of this second exposure pathway may change in the future as the magnitude of this pathway increases.

To extend the knowledge about the mercury intoxication on miners, Ekawanti and Krisnayanti (2015) concluded that after five years of exposure to mercury, people in Sekotong area ASGMs, both miners and non-miners, showed proteinuria and low hemoglobin and hematocrit concentrations due to chronic mercury intoxication as indicated by high urinary and hair mercury levels. Where 61 % of the miner's urine and 81% of the miner's hair content Hg which were in alert and high levels. All participants (100 people) in the present study were directly exposed to mercury, either as workers (miners) or as family members (non-miners) living in the contaminated atmosphere, including children that had direct contact with mercury from mercury panning after school and standing in close proximity to burning processes. Most of the women were of reproductive age, which means that their pregnancies were also at risk, as mercury affects intrauterine growth development, especially brain development. The duration of exposure to mercury contaminants was an average of 5.4 years. This period was much shorter than the 14.8 years needed to show specific clinical manifestations in previous reports. The factors regarding the occurrence and severity effects of mercury on human health include: the chemical form and dose of mercury; the age or the developmental stage of the person exposed, and the duration and exposure route, including inhalation, ingestion, and dermal contact. Fish consumption patterns can also increase the chance of mercury exposure when fish and seafood are contaminated with mercury.

Further study in West Sumbawa Regency ASGM, Krisnayanti et al. (2016) stated that the ASGM sector in the West Sumbawa Region has a large migrant worker population, which is an important economic support to the local community. The average income of the miners before working in the ASGM was € 2.19/day or less and after changing the job become miner, the average income was € 31.99/day or more. The migrant workers stated that the reason they were coming to West Sumbawa Regency is definitely for earning more money than in homeland (80%), and unemployment (20%). It is predicted that the amount of mercury use in Taliwang is more than 1.25 tonnes per day, its involve high mercury use and illegal mercury trading. These activities have affected the health of miners in a short time (less than 5 years), as evidenced by the high mercury residue on the bodies of miners (exposed) above the normal level permitted by WHO which is 1 mg/kg. The most common symptoms experienced by the miners were finger tremors and sleep disturbances. In addition, miners reported frequent excessive salivation, physical fatigue. On the neuro-psychological tests (matchbox and pencil tapping tests), miners had a high frequency of positive results, means chronic mercury intoxication had occurred.

Krisnayanti and Anderson (2013) concluded that a degraded environment in the ASGM areas of Lombok could potentially affect the sustainability of tourism on the island, the quality of food produced in ASGM areas, and the health of the population of the mining areas on Lombok. From this study it was underlined that long-time environmental risk associated with the uncontrolled discharge of tailings into the environment. Tailings from both areas (Lombok and Sumbawa) will likely contain an elevated concentration of soluble mercury a form that can contaminant the environment (specifically water). The uncontrolled discharge of tailings therefore, represents the single greatest threat to the long-term sustainability of ASGM in Lombok. However, this report confirmed that the economic contribution of ASGM to the local economy was positive. An estimated 22,446 direct jobs and economic activity of US$22 million per year can be attributed to ASGM across three mining areas on Lombok. The overall conclusion of the cited report was that ASGM was positive for Lombok, and that the sector should be allowed to develop under a framework where mining was regulated and became subject to district government control, and where environmental protection was implemented through a system of environmental monitoring and waste management.

It proved that ASGM activity in Sekotong-Lombok and Taliwang-Sumbawa has affected environment and human health. Furthermore, Krisnayanti and Anderson (2014) suggested to use gold phytomining as an option to eliminate mercury contamination to pollute river and sea by handling the tailings, From their prelimary study, it was suggested that “gold phytomining is a promising technology to be used on gold tailings in Indonesia”. Further research on gold phytomining had been extended by Krisnayanti et al. (2016), and it found that the gold concentrationin plants (tobacco) was considerably lower that the target of 100 mg gold/kg dry biomass which has been set in previous literature. To achieve this target, the bioaccumulation factor needs to be about 100 times greater on this area of tailings, or lower if tailings with a higher concentration for gold can be found. A published model for gold phytomining suggests that a gold concentration of approximately 50 mg/kg can be expected from ‘soil’ with a gold concentration of 1 mg/kg. There is therefore considerable opportunity for optimisation of treatment of the plants to promote increased gold uptake in future studies.

Conclusion and Recommendation

The impact of ASGM on increasing economic activity leading to jobs, income and opportunities for social development is positive. However, there is risk of contamination in soil and plants environment through mining activity and high Hg concentration discovered in human body in a short time of ASGM activity. The technology practiced by the ASGM miners to recover gold from rock is generally appropriate; amalgamation is no longer used, and cyanidation is both efficient and safe if usedcorrectly. Environmental risk is mostly apparent atthe end of the mining cycle, when cyanidation tailings is discharged into the environment with no strategy to contain or manage the contaminant burden of the waste. The health and safety record of mining should be regulated and improved. But the single greatest environmental risk apparent for the ASGM sector in Lombok is the uncontrolled discharge of tailings into the environment. Tailings management must be implemented to ensure the sustainability of ASGM and to ensure that mining practices do not impact on the future sustainability of tourism and agriculture on Lombok and Sumbawa. To ensure future sustainability of ASGM, it was suggested that ASGM in Lombok and Sumbawa should be regulated.

The environmental sustainability of mining can be better regulated within legalised areas, and tailings management plans implemented. An environmental monitoring programme should be implemented throughout the current ASGM areas to monitor the concentrations of mercury in soil and water. Environmental monitoring will define unacceptable risk and allow for advanced implementation of remedial measures before an uncontrollable disaster occurs. In addition, the science and technology to increase the metal concentration in plants exists, and must be further demonstrated to miners and farmers in ASGM communities. The processing system proposed must also be further demonstrated, to allow for more complete assessment of the feasibility of gold phytomining or agromining for sustainable tailings management in ASGM areas. The economic case for phytomining will only become apparent when a saleable value can be put on the final product from a scaled-up phytomining operation.

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