JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 10, Number 4 (July 2023):4611-4627, doi:10.15243/jdmlm.2023.104.4611
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Socio-economic baseline, economic feasibility study and processing activities ASGM in Obi Island, South Halmahera District, North Maluku Province, Indonesia

Angella Natalia Ghea Puspita*, Yanto Sudiyanto, Irwan Haryanto, Quinta Nadya Madra

Center of Research Mining Technology, National Research and Innovation Agency, PUSPIPTEK Serpong, Indonesia

*corresponding author: angella.natalia.ghea.puspita1@gmail.com

Article history:
Received 3 October 2022
Accepted 12 February 2023
Published 1 July 2023

Keywords:
ASGM
feasibility study
gold processing
mercury
socio-economic

Abstract

Artisanal and small-scale gold mining (ASGM) is the mining of gold deposits with simple physical and chemical characteristics using simple equipment and technology. In 2005, total mercury release in the environment in ASGM was more than twice from this sector, around 35% of total mercury, with an annual estimate at 727 tons, becoming the largest global resource of anthropogenic mercury release. In Indonesia, total mercury released to the environment is estimated at 340 metric tons per year and also among the top 3 global emitters of mercury, with 57.5% from the ASGM sector, 60% is emitted to the air, 20% to water, and the remaining 20% to land. The location of artisanal and small-scale gold mining (ASGM) in this study are in Anggai Village and Air Mangga Village in Obi Sub-district, South Halmahera District, North Maluku Province. Amalgamation has been the preferred method for treating the gold ores in both Anggai and Air Mangga Villages. The methodology provides a suggested approach for collecting and analyzing data and guidance for analyzing policy, regulatory, and institutional aspects and health aspects in the ASGM sector, mainly covering the socio-economic of ASGM research methodology. An assessment of the practicality of a proposed plan or project is also called Feasibility Study. The objective of this research was to describe the socio-economic impact and feasibility of gold processing of ASGM in Obi Island, South Halmahera District, North Maluku Province.

To cite this article: Puspita, A.N.G., Sudiyanto, Y., Haryanto, I. and Madra, Q.N. 2023. Socio-economic baseline, economic feasibility study and processing activities ASGM in Obi Island, South Halmahera District, North Maluku Province, Indonesia. Journal of Degraded and Mining Lands Management 10(4):4611-4627, doi:10.15243/jdmlm.2023.104.4611.

Introduction

Gold is a chemical element that has the symbol of Au with an element number of 79 in the Periodic Table of Elements. Gold is traditionally used for jewellery and decoration and as an advanced material for electronic components and devices and has unique characteristics such as an attractive shine, high electrical and thermal conductivity, resistant corrosion, and very high market value (ITB, 2020). Gold is one of the most valuable materials, but it is extracted under circumstances that are hazardous to artisanal and small-scale gold miners' health. A standard gold extraction method uses liquid mercury, leading to high exposure in workers (Taux et al., 2022). Gold is one of the most sought-after and demanded elements in international trade and the most exploited precious metal in world mining production (Mestanza-Ramón et al., 2022).

Artisanal and small-scale gold mining (ASGM) directly and indirectly employs over 100 million people in over 70 countries. An estimated 10-15 million people work directly on ASGM activities worldwide, out of which 4-5 million are women and children, and this is increasing in Latin America every year. ASGM produces 12 to 15% of the gold in the world (Vergara-Murillo et al., 2022). Artisanal gold mining was illegal in most African countries until the 1990s. It had grown from virtually nothing to exports of at least 446 tons of gold worth approximately US$17.94 billion to Dubai in 2016, with some 10 million Africans working in these often-hazardous mines, up from approximately 1.8 million in 1999 (Grynberg et al., 2021).

Artisanal and Small-Scale Gold Mining (ASGM) is the mining of gold deposits with simple physical and chemical characteristics using simple equipment and technologies. Often, ASGM operations do not have legal permission from the government or local authorities in accordance with applicable laws and regulations to conduct their operation (ITB, 2020). In 2005, total mercury release in the environment in ASGM was more than twice from this sector, around 35% of total mercury, with an annual estimate at 727 tones, becoming the largest global resource of anthropogenic mercury release. In Indonesia, total mercury released to the environment is estimated at 340 metric tons per year and also among the top 3 global emitters of mercury, with 57.5% from the ASGM sector, 60% is emitted to the air, 20% to water, and the remaining 20% to land (UNEP, 2013). In many low and middle-income countries that develop ASGM practice, approximately 15 million people, with three million women and children, participate in ASGM activities. These countries have limited or no compliance mechanisms regarding small-scale mining sectors' health and safety issues (Komatsu et al., 2020). In Ghana, ASGM contributes significantly to Gross Domestic Product (GDP) and makes this activity an important source of employment and income for miners and their dependents. Even though, represent ASGM relatively small proportion, only 10% of Ghana annual gold mining production, the ASGM sector grows, which affects the livelihood of the increasing number of people each year (Wilson et al., 2015). One of the reasons is the need for more government laws and government programs against artisanal mining activities. ASGM has been a concern in many countries in the world (Suhartini and Abubakar, 2017).

A non-formal occupational sector in many rural parts of developing nations is Artisanal and small-scale gold mining (ASGM). This sector relies on unskilled labor to mine and process gold, which area of agricultural income alone cannot support community livelihoods. Although ASGM contributes to poverty alleviation and generates national income, it has also have associated negatively with social, environmental, and health issues. The International Labor Organization (ILO) reported that ASGM activities are labor-intensive, involve a small number of people, and rely on essential equipment. Globally, over 100 million people are directly or indirectly involved in ASGM for their livelihoods (Kyaw and Sakakibara, 2022).

ASGM activities in Indonesia have been practiced for hundreds of years, and greater increase in activity in the present day. Indonesia also entered the Top Ten gold producers worldwide, with total production in December 2020 reaching 13 tons, and host to a large number of ASGM business and operation facilities (Meutia et al., 2022). ASGM in Indonesia have several problems from the operation; there is the use of mercury in gold ore processing which have a negative impact on the health of miners and the environment in the long run; moreover, poor handling of the tailing produced from the operation causes an environmental impact. ASGM activities contributed to one of the heaviest mercury pollutions nationally and globally based on the amount of mercury released. To reduce and eliminate the use of mercury in ASGM operations, the Indonesian Government, with Presidential Decree (Peraturan Presiden) No. 21 of 2019 on National Plan to Reduce and Eliminate Mercury (Rencana Aksi Nasional Pengurangan dan Penghapusan Merkuri or known as RAN-PMM) containing strategies, activities, and targets for reducing and eliminating mercury, which is prioritized on the following aspect: (a) manufacture, (b) energy, (c) artisanal and small-scale gold mining, and (d) health.

Sustainable development in gold mining has received significant attention in the last decade, including the legitimate Community Mining Area/WPR ("Wilayah Pertambangan Rakyat") promoted by the government. However, implementing sustainable development in this industry has become a complex dilemma. Research on the potential for other types of business income is needed to ensure miners' legal but sound livelihood. In order to minimize the amount of illegal ASGM activity, it is considered adequate to organize mining actors into co-operatives and provide financial assistance. This condition would involve supporting them in switching to other types of businesses while also providing environmental education about the adverse effects of mercury use and adapting appropriate technology to be used in its place (Meutia et al., 2022).

Ministry of Environment and Forestry (KLHK), with the Agency for Assessment and Implementation Technology or BPPT (known as BRIN) and the United National Development Programme (UNDP), support this action by creating Global Opportunities for Long-term Development Integrated Sound Management of Mercury in Indonesia's Artisanal and Small-Scale Gold Mining (GOLD ISMIA) Project. The objective of this project is to reduce/eliminate mercury releases from the Indonesia ASGM sector by (1) strengthening institutions and the policy/regulatory framework for mercury-free ASGM, (2) increasing the access of mining communities to enable the procurement of mercury-free processing technologies financially, (3) increasing the capacity of mining communities for mercury-free ASGM through the provision of technical assistance, technology transfer and support for formalization, and (4) raising awareness and disseminating best practices and lessons-learned on mercury phase-out in the ASGM sector. This project has selected six priority project locations of ASGM activities; there are located in Kulon Progo District (DI Yogyakarta Province), Kuantan Singingi District (Riau Province), Sekotong District (West Nusa Tenggara Province), Hulawa District (North Gorontalo Province), Tatelu District (North Sulawesi Province) and South Halmahera District (North Maluku Province) (ITB, 2020).

In Indonesia, total mercury released to the environment is estimated at 340 metric tons per year and also among the top 3 global emitters of mercury, with 57.5% from the ASGM sector, 60% is emitted to the air, 20% to water, and the remaining 20% to land. Moreover, small-scale miners, non-registered, informal operations located in remote areas with a total of 300,000 to 500,000 people, have a source of income significant from gold mining and processing (UNEP, 2013). The highest sources of mercury emission and released to ASGM, oil and gas production, coal-fired plants, incinerations and open burning, and waste disposal, based on the result of studies of mercury inventory 2012 in Indonesia, was around 339,250 kg Hg/year, which about 59.37% was released into the air, about 15.5% was released into the water and about 14% released into soil/sediment. Approximately 57.5% of these emissions came from the ASGM sector, with a total emission of about 195 tons /year or about 20% of total ASGM global emissions in that year. Total gold production in Indonesia is 128 tons, with estimated production from ASGM is 20% or around 25.6 tons with a ratio of Hg:Au for the amalgamation process is about 1.3:1 (Hg:Au) to 5:1 (Hg:Au), which means estimated mercury emission by ASGM at 2018 is around 33.28-128 tons (ITB, 2020).

According to BPS data, miners are officially registered miners only, both from mines and artisanal mines. In 2009, it was estimated that there were 4,000 illegal gold mining workers at three locations in Sekotong Sub-district, West Lombok. In 2017, after banned the use of mercury, the number of gold miners was much reduced. There are currently around 200 semi-active miners at Buwun Mas Village, West Lombok. In Kulon Progo, Kuantan Singingi, and North Gorontalo are estimated to have around 100-200 active miners. Meanwhile, in North Minahasa and South Halmahera, it is estimated that more than 1.000 active miners are using mercury (ITB, 2020).

Obi Island is located in South Halmahera District, North Maluku Province. Mining activity in Obi Island has occurred since 1995. The presence of a high concentration of gold in Obi was immediately known to the locals due to the exploration activity of a mining company that conducted drilling and surveying on the location. Nowadays, gold mining and processing is the main occupation for the majority of the people living in Anggai Village and Air Mangga Village, whose locations reside near the mining sites. The location of artisanal and small-scale gold mining (ASGM) in this study are in Anggai Village and Air Mangga Village in Obi Sub-district, South Halmahera District, North Maluku Province. Based on BPS statistics of South Halmahera Regency in 2020, Obi Sub-district consists of 9 villages. Five mining location coordinates in Anggai Village and three mining location coordinates in Air Mangga Village were defined for this purpose.

In Air Mangga Village, known as ‘Spidang’ is located quite far (around 3 km) from the village area; these locations are muddy and have steep terrain, 4-wheel drive vehicle is required to access the mining site. There are 100 mining pits, and not all of them produce gold. Similar to Anggai Village, the mining pits in Air Mangga Village take some time before being able to produce gold, as an adequate number of gold-bearing ores are not easy to find during the digging. One of the unique cultures in Spidang is that when a mining pit is able to produce gold, other miners who are not the owner can ‘join’ to work in that particular mining pit, taking around 1-2 sacks of ore. In return, when the mining pits owned by those miners are harvesting, others may also join in to take some ores from it. One problem of Spidang is the disorganization of mining pits in this area. One mining pit can be very close to another, resulting in the two pits converging under the ground. This often creates conflict among miners who fight over the right to ores inside the pit. The condition is different in the mining site in Anggai Village, which has already established a rule that every new mining pit should have some distance away from the existing ones. Even if there is a conflict here, the issue is quickly resolved with the help of Cooperative (“koperasi”) in Anggai Village.

The methodology provides a suggested approach for collecting and analyzing data and guidance for analyzing policy, regulatory, and institutional aspects and health aspects in the ASGM sector, mainly covering the socio-economic of ASGM research methodology. The methodology will assist countries in effectively developing steps to facilitate the formalization or regulation of the artisanal and small-scale gold mining sector, as well as other requirements of the National Action Plans (NAP). This information can also be used to address wider national and regional development challenges (UNITAR, 2018).

In Ecuador, large-scale mining has been considered a strategic activity for the economic and social development of the country when it has consolidated as a sector with an important projection for the dynamization of the economy. The activity of Au mining or large-scall mining is considered a strategic activity with an increasingly strong presence in the framework of the country’s productive matrix, not only because of the important economic and employment generation involved but also because of the relevant role it plays in attracting foreign direct investment, an aspect which has change over time (Mestanza-Ramón et al., 2022). Brazilian Amazon has had significant social, economic, and environmental impacts in recent years. Deforestation in the Amazon region, which ASGM causes, has reached the highest value since beginning in 2015. The low-cost technique is chosen by illegal small-scale miners associated with the use of mercury, cause-effect short and long-term consequences for forests, soils, watersheds, animals, and humans (Queiroz et al., 2022). Artisanal and small-scale gold mining (ASGM) has become part of the livelihood strategy for a large section of the rural population in Burkina Faso. In some areas of the country, two out of three households have at least one family member working at an artisanal or small-scale mine (Brugger and Zanetti, 2020).

While artisanal-scale mining (ASM) is defined as “a subset of SSM”, Small Scall Mining is defined only by the limits of its scale or production, falling in the same product range but processing the characteristic of rudimentary mechanization, inefficient reclamation, unhealthy and unsafe work condition and exploitation of labor moreover. When ASM is performed responsibly (losing its negative aspects), it simply becomes SSM. SSM has the potential to be an active, positive stakeholder in the mineral resources market (Marin et al., 2016).

Based on data from UNDP, ASGM is an important source of income for 300,000 Indonesian miners. ASGM produces gold in rural areas and can earn as much as 70% or more of the standard international price. With these considerations in mind, people living in remote areas often view small-scale gold mining as a way out of poverty. The actors who participate in gold mining include agricultural and fishery workers who work part-time and require additional income in order to sustain their livelihoods. Meanwhile, for some communities, ASGM activity is the main source of income by which to support their daily lives (Meutia et al., 2022). An assessment of the practicality of a proposed plan or project is also called a feasibility study. Feasibility is also analyzing the viability of a project to determine whether the project or venture is likely to succeed. The study was also designed to identify potential issues and problems that could arise while pursuing the project (Investopedia.com, 2022). This study aimed to describe the socio-economic baseline and feasibility study of gold processing ASGM in Obi Island, South Halmahera District, North Maluku Province.

Materials and Methods

Study area

The locations of ASGM in this study are in Anggai Village and Air Mangga Village in Obi Sub-district, South Halmahera District, North Maluku Province. According to BPS-Statistics of South Halmahera Regency in 2020, Obi Sub-district consists of 9 villages, namely Anggai Village, Sambiki Village, Jikotamo Village, Laiwui Village, Button Village, Baru Village, Akegula Village, Kawai Village and Air Mangga Village. Eight villages are located on Obi Island, and one village, Laiwu Village, the capital of Obi Sub-district, is located on Bisa Island. Obi is one of 30 sub-districts in South Halmahera District and has an area of 1,073.15 km^2 or 12.22% of the total area of South Halmahera District. Anggai Village has an area of 123.7 km^2 or 11% of the area of Sub-district, while Air Mangga Village has an area of 129.5 km^2 or 12% of the total area of Obi Sub-district. Anggai Village and Air Mangga Village are adjacent villages located on the North Coast of Obi Island.

The types of transportation between villages that can be used in both Anggai Village and Air Mangga Village are in the form of land transportation and water transportation, considering that their locations are in the coastal area.

Mining location

Field survey activity was conducted in each village, at which location coordinates were taken for future mapping of the areas. Five mining locations were defined for this purpose. The coordinates of gold ore processing facilities and the location for a future instalment of mining processing plant were also taken. The coordination of mining locations in Anggai Village and Air Mangga Village is presented in Table 1. The mining location in Anggai Village ± 1.5 km from residential areas. Meanwhile, the mining location in Air Mangga Village is ± 4 km from residential areas. Access to the mining location is in the form of a dirt road. Roads connecting the mining sites and processing locations are in the form of a narrow footpath.

Table 1. Mining and processing location of ASGM in Anggai Village and Air Mangga Village.

No	Location	Village	X Coordinates	Y Coordinates
1	Anggai	Anggai	127° 43’ 29.4” E	127° 43’ 29.4” S
2	Anggai	Anggai	127° 43’ 29.4” E	01° 21’ 37.0” S
3	Anggai	Anggai	127° 43’ 26.3” E	01° 21’ 33.7” S
4	Anggai	Anggai	127° 43’ 30.8” E	01° 21’ 35.4” S
5	Anggai	Anggai	127° 43’ 35.2” E	01° 21’ 40.5” S
6	Air Mangga	Air Mangga	127° 44’ 5.226” E	01° 23’ 30.259” S
7	Air Mangga	Air Mangga	127° 44’ 4.384” E	01° 23’ 32.669” S
8	Air Mangga	Air Mangga	127° 44’ 3.801” E	01° 23’ 32.668” S

Anggai Village

There are five ASGM mining location points which are mapped in Anggai Village. A photo of mining conditions in Anggai Village is shown in Figure 1, while a photo of processing conditions is shown in Figure 2. The mining site in Anggai Village is located on a flat to hilly topography at an altitude of 8-27 meters above mean sea level (mamsl). The mining location can be reached via dirt roads and trails. The mining location is 91-240 m by local roads and 1209-1270 m to the location for future processing plants via footpaths and local roads.

Figure 1. Mining site in Anggai Village.

Figure 2. One of the processing facilities in Anggai Village.

Air Mangga Village

ASGM mining in Air Mangga Village is located in an area with hilly and mountainous topography. The mining location in Air Mangga village is at an altitude of 420-470 mamsl. This location is quite difficult to reach because of the limited road access in the form of footpaths. The mining location is ± 1,000 m away from the nearest footpath and has a straight distance of 3,000-3,400 m from the location of the future processing plant in Anggai Village. The mining conditions in Air Mangga Village are shown in Figure 3.

Figure 3. Mining location in Air Mangga Village.

Data collections

Data were collected through observation, deep interviews, and questionnaires delivered to the ASGM miners and related parties in the regional site. The mercury and gold mass balance inventories in the ASGM sites were measured through ore sampling and analysis. Process parameters for amalgamation were used as the basis for the cost calculation and derived from various approaches, including primary data from metallurgical test works and secondary data from available literature/previous related projects.

Data processing

Data collected from the observation, interview and questionnaires were processed by Microsoft Office Excel as a tool for calculating and presenting the results. The data used were primary quantitative data from the observation and in-depth interviews, which are part of production costs. The calculation of processing costs using the amalgamation process was divided into several parts consisting of mercury cost, electricity cost, and LPG fuel cost.

Data analysis

Data analysis was presented to ASGM and local representatives to compare existing and current ASGM practices in Obi Island. An economic feasibility study was conducted to test the feasibility of the business process and gold processing activity used in Anggai Village and Air Mangga Village.

Gold ore processing activity

Amalgamation has been the preferred method for treating the gold ores in both Anggai Village and Air Mangga Village. As previously described, the ore sacks collected from the mine shaft are transported to the processing facility. In Anggai Village, there is one area where many processing facilities are concentrated in this location, as shown in Figure 4. In Air Mangga Village, on the other hand, there is no processing facility nearby; therefore, all ore mined from this village must be brought up to the processing facility in Anggai Village.

Figure 4. Processing facilities in Anggai Village, which are concentrated in one big location.

Results

Social economy baseline

South Halmahera Regency is the newest regency in North Maluku Province, which has various potential for mineral/commodities. Anggai Village and Air Mangga Village in Obi Sub-district, which are the main study areas, are known to have deposits of gold.

Respondent characteristic

The characteristic of respondents discussed here related to age, family status, gender, population status and education status (Figures 5, 6, 7, 8 and 9). Total of respondents were 47 respondents, 30 respondents from Anggai Village, and 17 respondents were from Air Mangga Village.

Age of respondents

Most of the respondents in Anggai Village and Air Mangga Village are, on average, aged between less than 25 to 45 years old (Figure 5). In Mongolia, woman miners aged between 15-35 work in ASGM (Steckling et al., 2011). So, the majority of ASGM miner's age is between underage to productive age.

Status in the family

Most of the respondents in Anggai Village and Air Mangga Village are heads of the family (Figure 6).

Gender

Most of the respondent gender in Anggai Village and Air Mangga Village is male, with an average female presentation of 12% (Figure 7). Long et al. (2015) reported 88% of men in Kejetia, Ghana worked in mining.

Population status

Most of the respondent's population status in Anggai Village and Air Mangga Village are immigrants from other districts, regencies, or from outside North Maluku (Figure 8).

Education status

Most of the respondent's education status in Anggai Village and Air Mangga Village did not attend school. Average miners in ASGM did not have an education (Figure 9). Long et al. (2015) reported that in Kejetia, Ghana, the percentage of women with no education in women miners increased in higher area groups.

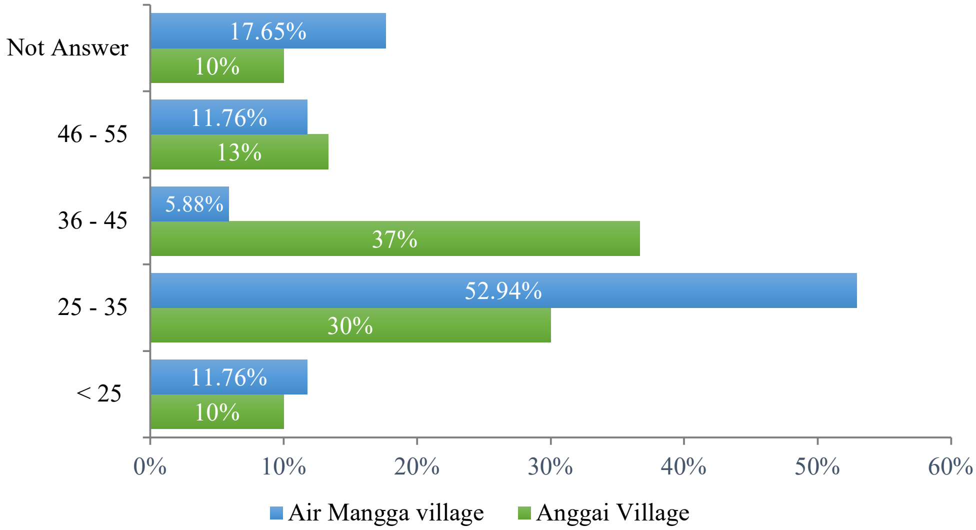

Figure 5. The age distribution of the respondents in Anggai Village and Air Mangga Village.

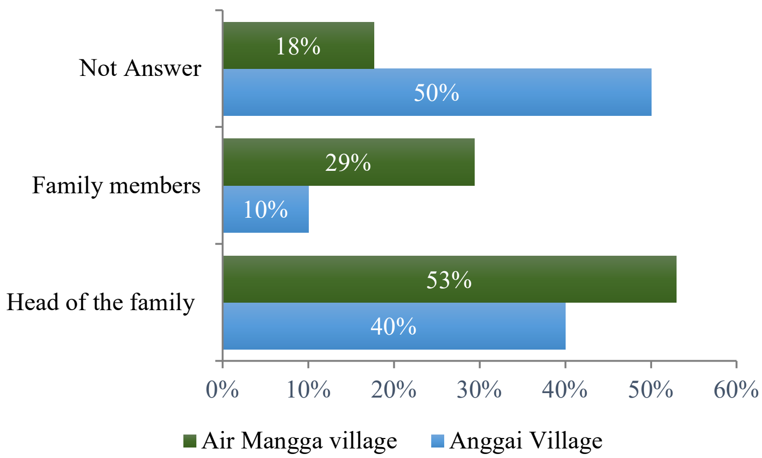

Figure 6. Respondent's status in family in Anggai Village and Air Mangga Village.

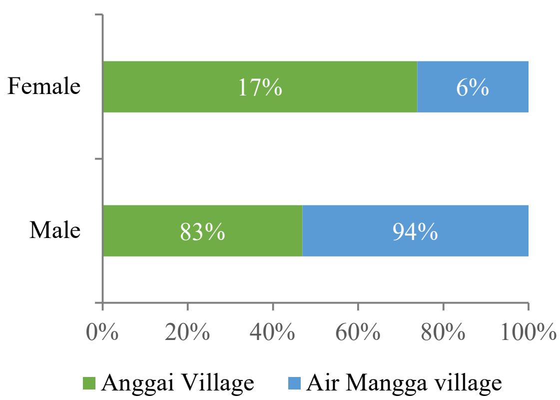

Figure 7. Details of respondents' gender in Anggai Village and Air Mangga Village.

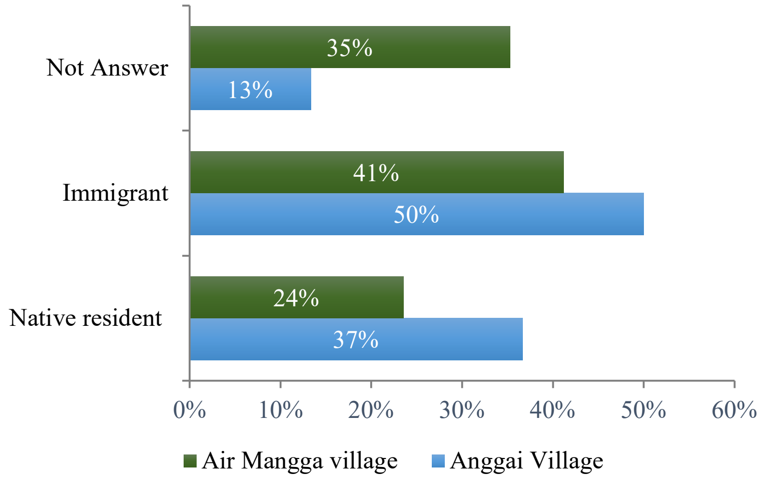

Figure 8. The details for the resident status of respondents in Anggai Village and Air Mangga Village.

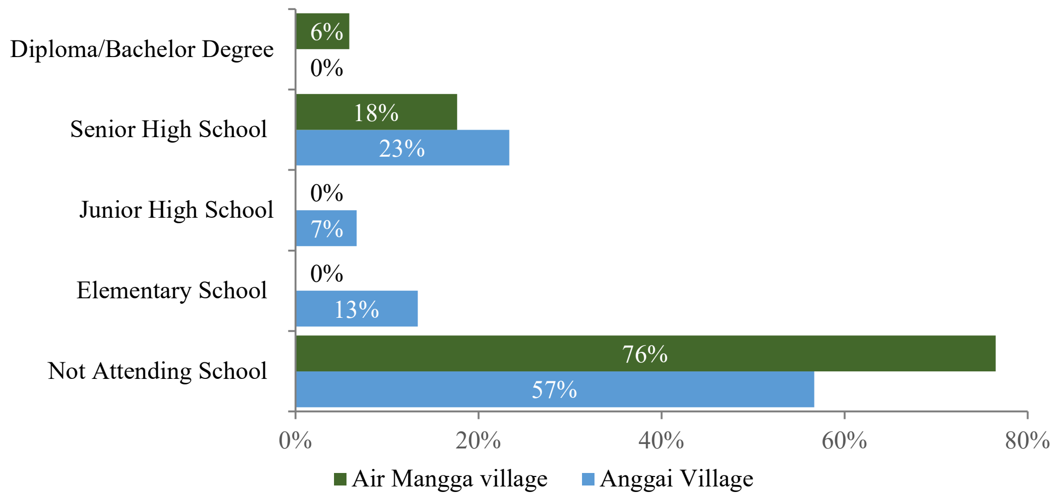

Figure 9. Profile of education level of the respondent in Anggai Village and Air Mangga Village.

Data of socio-economic

A socio-economic baseline survey of Anggai Village and Air Mangga Village was carried out to obtain the data of respondent's livelihood, income, monthly from gold mining activity and respondent's perception of monthly income from mining activity.

Livelihood

Most of the respondent's main livelihood in Anggai Village and Air Mangga Village is miners (Figure 10). According to UNDP data, ASGM is an essential source of income for Indonesia's estimated 300,000 miners (Meutia et al., 2022).

Income

Most of respondent's income from their main livelihood is < Rp.1.000.000, - (Figure 11).

Monthly income from gold mining activity

Most of respondent's income from mining activity is Rp.1.000.000-Rp.2.500.000 (Figure 12). ASGM producers in rural areas can earn as much as 70% or more of the standard international price. The actors participating in gold mining include agricultural and fishery workers who work part-time and require additional income to sustain their livelihoods (Meutia et al., 2022).

Respondent's perception of monthly income from mining activity

Most of respondent's perception of monthly income from the gold mining activity is satisfactory (Figure 13). Because people living in remote areas often view small-scale gold mining as a way out of poverty (Meutia et al., 2022).

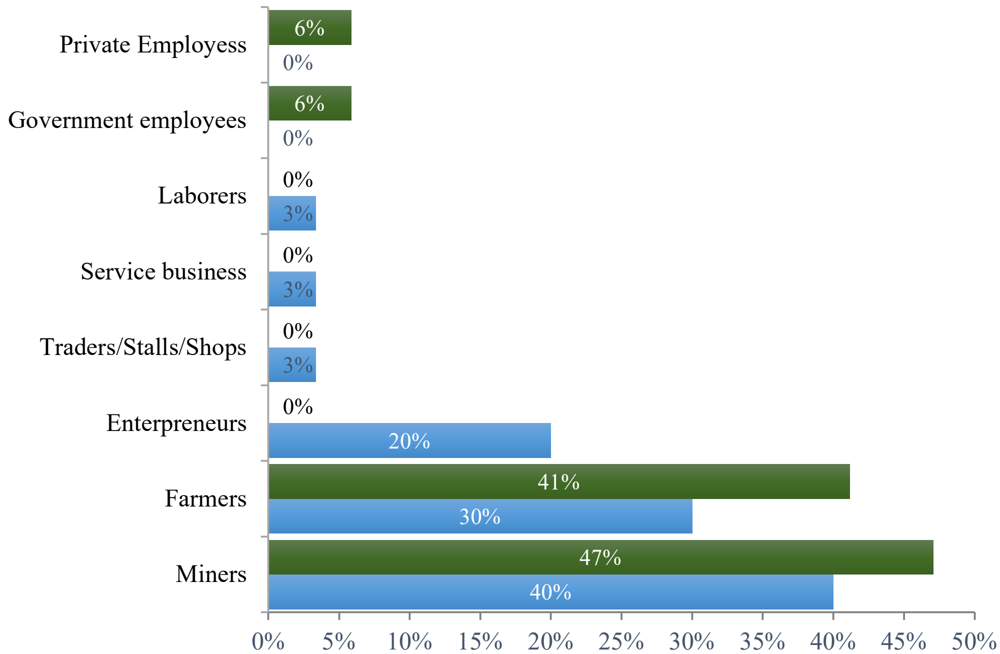

Figure 10. Profile of the respondent's main livelihood in Anggai Village and Air Mangga Village.

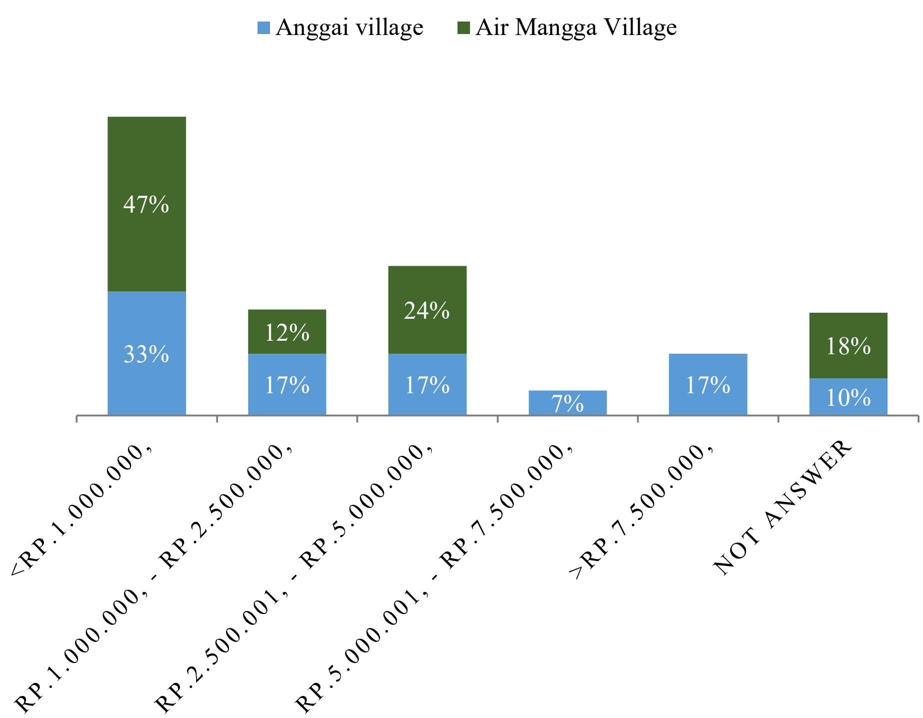

Figure 11. Respondent's income from main livelihoods.

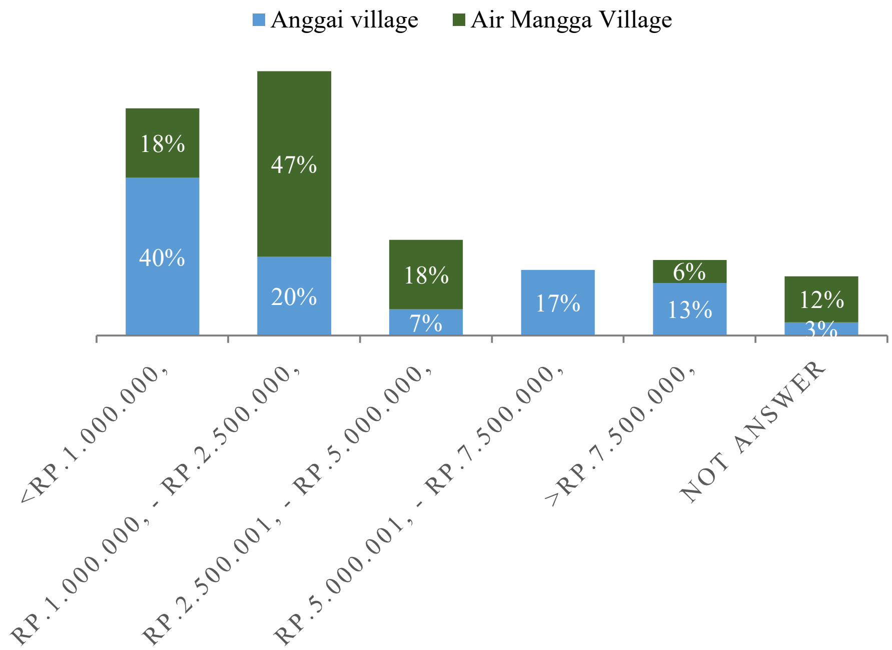

Figure 12. Respondent’s income from mining activity.

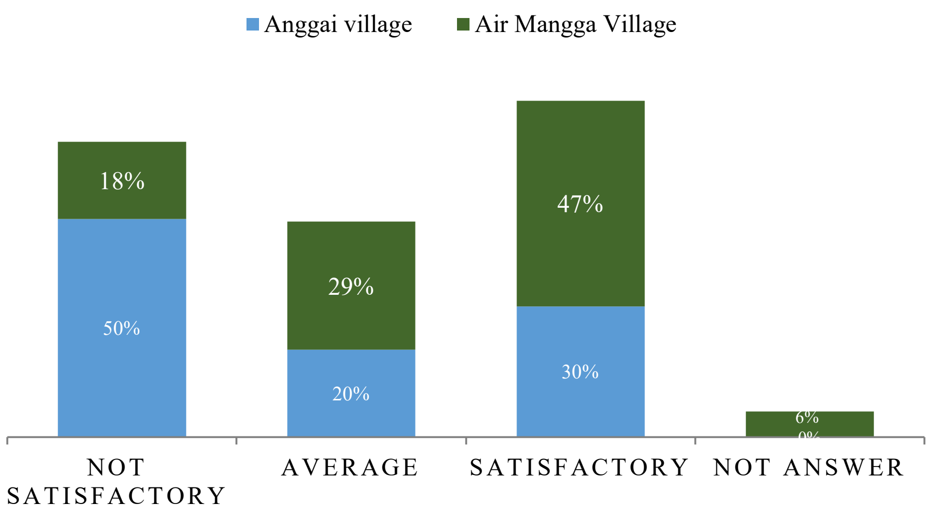

Figure 13. Respondent’s perception of monthly income from the gold mining activity.

Socio-cultural aspect

The mutual cooperation system is still often found at community work events and in the agricultural business, as well as reflected in village meetings for decision-making by deliberation to reach a mutual interest.

Existence of mutual cooperation activities

Most of respondent’s perceptions of the existence of mutual cooperation activities exist until now (Figure 14).

Forms of mutual cooperation activities

Most of the respondents said that mutual activities form in the two villages is cleaning up the environment (Figure 15).

Existence of mining group

Based on the result in Figure 16 respondent’s responses on the existence of mining groups in Anggai Village show 19 people (63%) did not answer, 6 people (20%) existed, and 5 people (17%) did not exist. Meanwhile the existence of the mining group from Air Mangga Village, 7 people (41%) existed, 6 people (35%) did not answer, and 4 people (24%) did not exist.

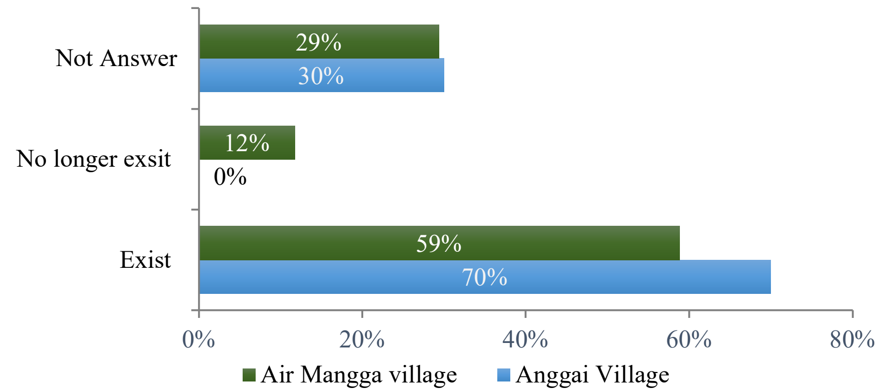

Figure 14. The profile of perception on existence of mutual cooperation activities.

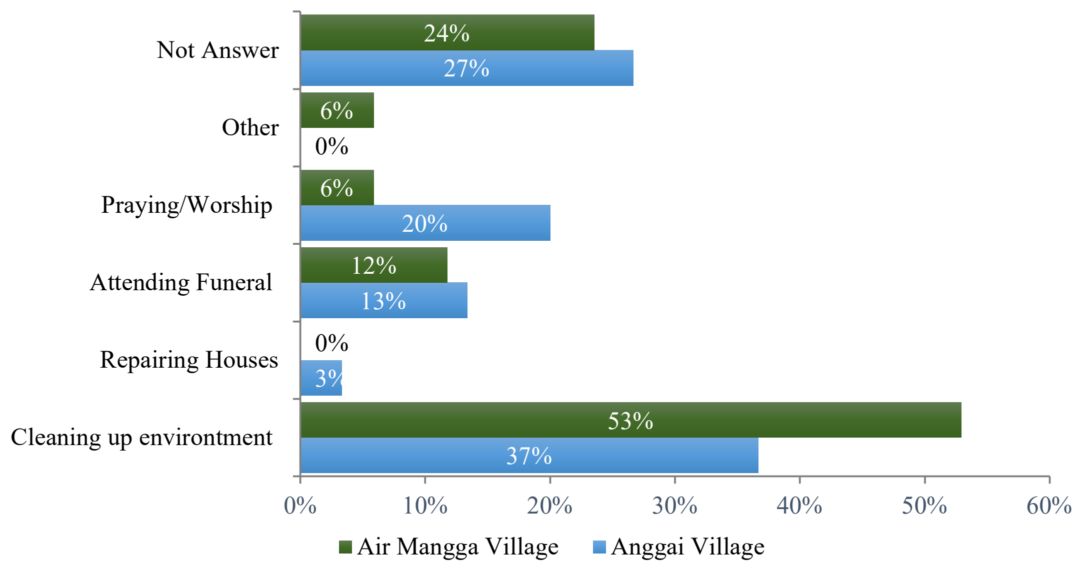

Figure 15. Mutual activities form in two studied villages.

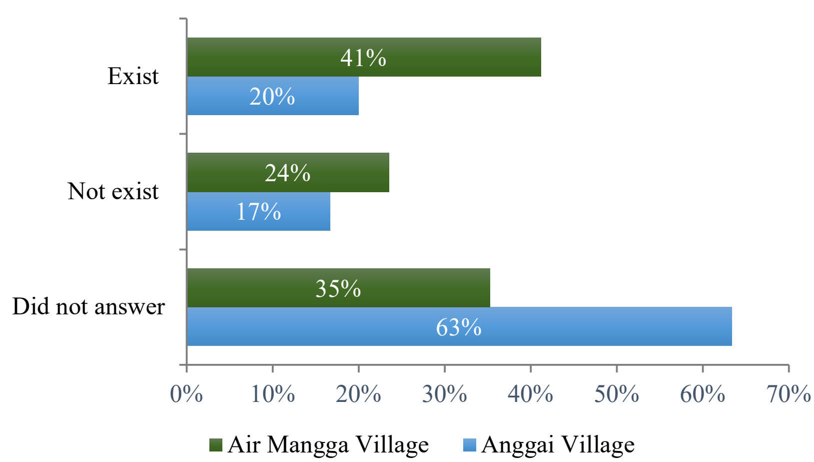

Figure 16. Respondent’s response on the existence of a mining group in two villages.

Feasibility study

In this section, the total cost and total profit were calculated from the amalgamation method for treating the gold ores in both Anggai Village and Air Mangga Village. Data presented in Table 2 were used as the basis for the cost calculation. The data are derived from various approaches, including primary data from the metallurgical test works and secondary data from available literature/previous related projects.

Table 2. Process parameter for cost calculation amalgamation.

Process Parameter	Unit	Amalgamation
Recovery Au	(%)	40
Assumption for LPG 12 kg cylinder required to smelt carbon ash	Maximum cylinders/ 2.5 kg carbon ash	
Diesel for max kVA	L	25.2
Hg consumption per tones ore	kg	0.5**

Note: (**) mercury usage is 23 kg with >90% Hg recycled.

Based on the pre-determined process parameters, the cost and benefit calculations are built up and presented in Table 3. Total cost, income and profit for amalgamation method that only employs one reagent (mercury) to complete its process.

Table 3. Cost, income and profit of amalgamation method.

Cost	Amalgamation
Electricity (IDR)	1,058,400.00
LPG for amalgam vaporization (IDR)	150,000.00
Mercury (IDR)	450,000.00
Sub Total cost (IDR)	1,658,400.00
Misc cost (17.5%) (IDR)	290,220.00
Total Cost (IDR)	**1,948,620.00**
Income	
Grade (g/t)	20.00
Ton (t)	1.00
Recovery (%)	40
Au produced (g)	8
Au price (IDR/g)	900,000.00
Income (IDR)	**7,200,000.00**
Profit (IDR)	**5,251,380.00**

Economic feasibility study

BC ratio

For business feasibility calculation of gold mining miners' activity, BC ratio was chosen as an instrument. If the value result is <1, then the business is not feasible to proceed; if the value result is >1, then the business is feasible (Prabawa et al., 2021).

$$\text{BC Ratio} = \frac{\text{Total Revenue}}{\text{Total Cost}}$$

From the calculation above, the BC ratio was calculated as follows:

$$\text{BC Ratio} = \frac{\text{Rp. } 7.200.000}{\text{Rp. } 1.948.620} = 3{,}695$$

BC ratio 3,695>1, so the business is feasible.

Amalgamation processing activity

Gold processing activity preferred in Anggai Village and Air Mangga Village is amalgamation processing activity. Before being processed for amalgamation, the rock material containing the gold ore is manually crushed using a hammer. This process of breaking rock is mostly carried out by local women in Anggai Village and Air Mangga Village. Usually, they are paid Rp. 5,000 for every sack of crushed ore. Children are often involved in this activity. According to a local woman, this activity (manually breaking rocks using a hammer) is carried out every day. While the husband is out at the mining sites, the wives and their children often help earn a living by taking part in this activity.

The crushed ores are then put back into the sacks and transferred to the nearby rod mills, locally known as "gelondong" for the amalgamation process. Usually, 2 sacks of crushed ore are added into each mill with an equal amount of water, after which the process is allowed to run for approximately 3 hours. After the completion of this stage, mercury is then added to the ground ore slurry. The amalgamation process is then continued to run for another hour. During this process, now liberated gold particles will react with the mercury to form gold amalgamation (Au-Hg), which can be easily separated from the slurry. After completion of the amalgamation process, the slurry inside the mills is poured into a bucket whilst carefully separating the gold amalgam from the slurry. In some processing facilities, ice cubes are often added to cool down the temperature of the collected gold amalgam. The gold amalgam is then filtered out using a piece of cloth. The final process is the burning of gold amalgam, which is conducted using a flame torch. A small of amount of borax is usually added to aid the process of separation between gold and impurities. The final product is in the form of impure gold bullion, usually in the range of 70-80% gold, as shown in Figure 17.

Aside from the amalgamation process, several cyanidation tanks are also observed in the processing location in Anggai Village. The waste solution from the amalgamation is usually processed further using the cyanidation process in these tanks. One cyanidation can process is equivalent to 250 sacks of ore. Carbons are added during the cyanidation to collect (adsorb) the dissolved gold in the solution. After the process is finished, the carbons are filtered, burned, and smelted to produce gold bullion as the final product. However, not all amalgamation processing facility re-process their waste solution using cyanidation. Some, instead, dispose of their waste solution directly into a pond. In the case of Air Mangga Village, since there is no processing facility in that village, the ore must be transported to the processing facility in Anggai Village.

Figure 17. Impure gold bullion as the final product of the ASGM activity in Obi Island.

This is usually done using motor taxis and pick-up trucks, which are paid around Rp.10,000 for every sack of ore transported. Out of the many processing facilities in Anggai Village, there is one that exclusively treats ores from Air Mangga Village. There are more than 20 processing facilities in Anggai Village. Each one consists of several mills (typically around 20-30 units) for the amalgamation process. The majority of the mill is in the form of a rod mill. The amount of reagent during the process or the time for the completion of amalgamation usually varies for each facility. From the measurement, 200-300 g of mercury is added to one mill during the amalgamation process, which roughly equals to 16-25 g per kg of ore (note: 12 kg of crushed ore is usually added to each mill). For the cyanidation tanks in Anggai Village, the process typically consumes 35 kg of cyanides and 50 kg of carbons per tons of ore processed. A flowsheet representing the gold processing method employed in the two villages is shown in Figure 18.

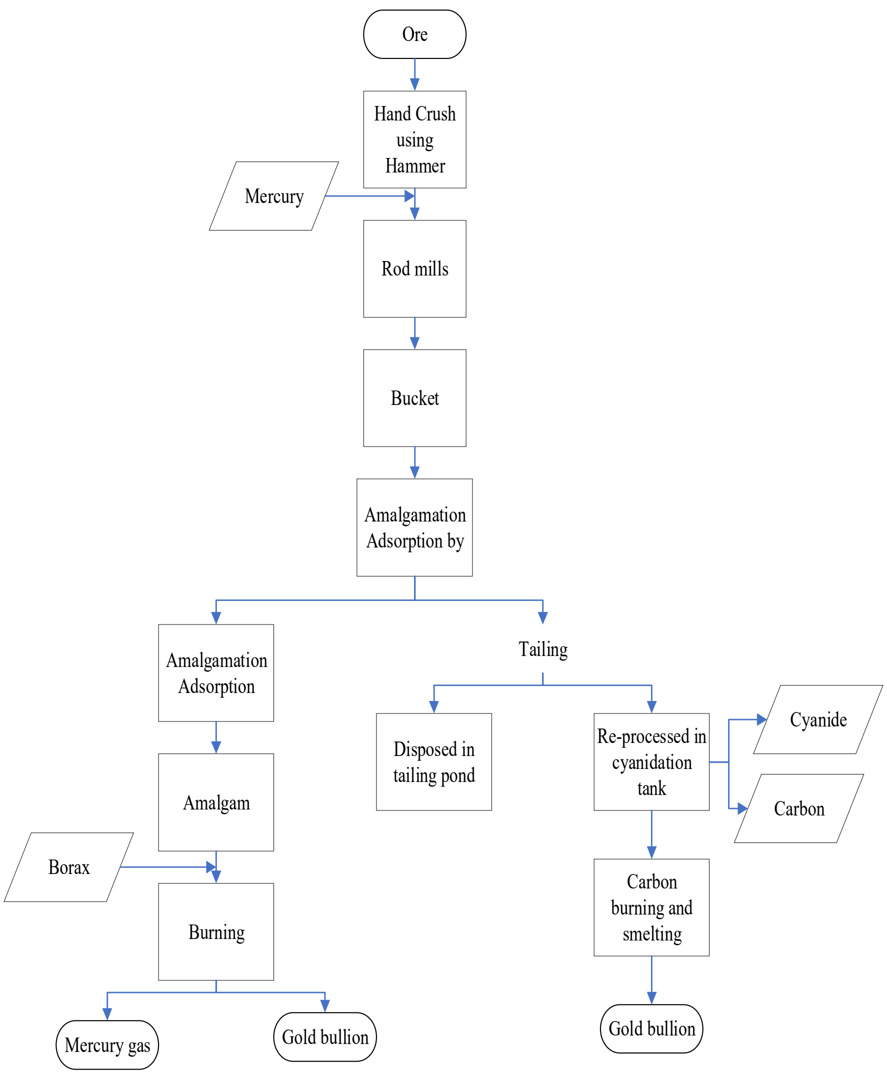

Figure 18. Flowchart of gold processing activity in Anggai Village and Air Mangga Village.

The amount of gold produced by the miners in Anggai Village and Air Mangga Village is termed ‘kacang’ or ‘batang’ equals to 0.1 g of gold produced. The gold amalgam, which initially weighed 2.89 g was converted to 0.59 g gold bullion after burning. Therefore, around 80% of gold amalgam is actually in the form of mercury, which will be released into the environment during the burning process.

The gold bullion is directly sold to gold collectors (or ‘pengepul emas’) residing in Anggai Village. Although the gold is priced relatively lower than the ones being sold outside of Obi Island, the miners feel that it is more convenient to just sell it directly to the gold collector in the village. One gram of gold is valued at Rp.610,000 by the gold collector. However, depending on the price of gold globally, it can change weekly or monthly. There are more than 10 gold collectors in Anggai Village and Air Mangga Village. On average, every gold collector can collect 1-2 kg of gold from the local miners (Figure 19), which accounts for around 10-20 kg of gold collected monthly from the miners in Obi Island. The gold is then shipped to Ternate via ship, where it will be then sold to other places at a higher price.

Figure 19. Massive gold bar accumulated from the gold bullion sold by the miner in Anggai Village and Air Mangga Village.

Discussion

Socio economic baseline

Respondent characteristic

Based on the result from Figure 5 until Figure 9, the respondent characteristics of 30 respondents from Anggai Village and 17 respondents from Air Mangga Village are most of the respondent's age is productive age with range age between 25-45 years with most of the status in the family is head of the family. Most of the respondents are male, and the respondents’ population status is immigrants not originally from Obi Islands. Most of the respondent’s education level is relatively low on average; this is indicated by the survey results, which show that most of the respondents in the two villages did not attend school and some only graduated from elementary school. In Ghana, from a total of 404 ASGM miners from the Tarkwa District, 75% were less than 40 years of age, with a mean age of 34 and only 30% of the miners were educated, and more than 50% were routinely involved in more than one activity (Calys-Tagoe et al., 2017).

Data of socio-economic

Based on the result from Figure 10 until Figure 13, most of the respondent’s socio-economic from Anggai Village and Air Mangga Village livelihood is miners, with most income <Rp.1,000,000; moreover, most of the income from mining activity in Anggai Village is from Rp.1,000,000, until Rp.2,500,000. Perceptions of the respondent regarding the income from the mining sector discussed with most of the respondents in Anggai Village is satisfactory with income from mining activity. Krisnayanti (2018) reported that the impact of ASGM on increasing economic activity leading to jobs, income, and opportunities for social development, is positive.

Socio-cultural aspect

The people of South Halmahera have an important history because the Sultanate of Bacan, together with the Sultanese of Ternate, Tidore, and Jailolo, formed a culture known as “Maloku Kie Raha”. In general, there are three local cultural influences in South Halmahera, namely: Ternate culture, Tidore culture, and Bacan culture, which includes the Bacan and Obi Island whose customs are gradually different. Ethnic groups in South Halmahera included the Tabelo Galela, Makian Kayo, Boton, Bajo, Bacan and migrants from Gorontalo and Java. The mutual cooperation system is still often found at community work events and in the agricultural business, as well as reflected in village meetings for decision-making by deliberation to reach a mutual interest. Based on the result from Figure 14 until Figure 16, the existence of mutual cooperation activities at Anggai Village and Air Mangga Village shows that most of the respondents (more than 50%) stated that mutual cooperation activities still exist and are well preserved. There are various forms of mutual cooperation activities in Anggai Village and Air Mangga Villages, namely cleaning the environment, repairing houses, religious events, and other activities. The forms of mutual cooperation activities that are often carried out by the community and respondents at the two villages can be summarized that most of the respondents in Anggai Village and Air Mangga Village carried out cleaning the environment. Moreover, the existence of a mining group among miners can facilitate the exchange of information, discussion, and tools for finding solutions when a problem arises. Most of the respondents regarding the existence of a mining group in Anggai Village and Air Mangga Village stated that their village has a mining group.

Economy feasibility study

Afandi et al. (2019) reported that at many ASGM spots, amalgamation and cyanidation gold processing plants are seen side by side with agricultural lands; thus, the tailings produced are released into rice paddies fields which have been casually used as a tailings pond leading to agricultural land contamination with no strategy to contain or manage the contaminant burden of the waste. The amalgamation process does not use cyanide as the leaching chemical but uses mercury metal as the chemical leaching reagent. Mercury extracts gold and silver from the gold ore. However, mercury is a heavy metal class, and exposure to it will cause health problems as well as it is not easily degraded by nature. In the amalgamation process, several process tools are used to support gold processing, such as a jaw crusher, roll crusher, ball mill etc. Some of them may overlap with cyanidation, while the rest (i.e., cyanidation tank) is not needed due to the nature of the amalgamation process itself.

In the amalgamation process, the cost of electricity is calculated based on the consumption of diesel to power the generator. After the amalgamation process is complete, the mud and mercury are separated. The mercury that is separated is already binding the gold and silver in it. Mercury is separated from the sludge by means of a parasitic filter cloth. If the mercury has been separated from the mud, then the mercury will be burned/smelted to separate the gold and silver from the mercury. The smelting of mercury uses fire from LPG (Liquid Petroleum Gas) as fuel.

The transition from amalgamation use in ASGM is to implementing cleaner processing techniques, including cyanidation. This transition is challenged by the existent division of labor, as different actors are involved. The processing center owners want to keep the use of amalgamation processes for the artisanal miners who pay for this service since it recovers only 30% of the gold, leaving 70% of the profit for the owners. However, some miners now recognize they can recover more gold using cyanidation, but in many cases, they cannot afford to wait two weeks to extract the gold and receive their money (Gonçalves et al., 2017).

Based on the calculation of the BC ratio from cost, income, and profit from the amalgamation process, BC ratio = 3.695, and the process is feasible. But the use of mercury in gold ore processing has a negative impact on the health of miners and the environment in the long run; moreover, poor handling of the tailing produced from the operation causes an environmental impact. So, mercury-free gold processing technology is needed, namely the cyanidation method. ITB (2021) calculated a comparison of the operating cost (OPEX) of the gold process by cyanidation and amalgamation process.

Electricity and chemical reagents are the two main operations costs that are compared between the two processes. The cost of the cyanidation process is more expensive than that of amalgamation, although cyanidation is, in most cases, more profitable. The following factor mainly drives this: the cyanidation process can produce (extract) more gold products and bring more income. Income from the gold extraction process is very much influenced by the recovery. Cyanidation can give 60-90% recovery depending on the mineralogy since it is normally >90% for oxide deposits. Therefore, 90% is chosen for comparative purposes as the average recovery for cyanidation based on the test work, and for amalgamation, it is assumed to be 40%.

The cost of cyanidation can still be lower by applying several strategies, such as recycling water that contains residual cyanide or using activated carbon that is less expensive but still has good adsorption properties and not necessarily excellent physical properties. To sum up, the difference in the profitability of cyanidation vs amalgamation is driven by several aspects (i.e., gold price, consumable price, % Au extraction, etc.). However, it is known that cyanide gives much higher Au extraction compared to mercury and with the current gold price, it is estimated that cyanidation gives ~106% higher profit than amalgamation, although the cost of cyanidation is also higher due to the use of multiple reagents (cyanide, carbon, lime, etc.) unlike amalgamation that only employ one reagent (mercury) to complete its process.

Amalgamation gold processing activity

Amalgamation has been the preferred method for treating the gold ores in both Anggai Village and Air Mangga Village. But the use of mercury in gold ore processing which has a negative impact on the health of miners and the environment in the long run, moreover poor handling of the tailing produced from the operation causes an environmental impact. So, mercury-free gold processing technology is needed, namely the cyanidation method. The result of calculation cost, income, and profit give more profitable from the amalgamation method and become the alternative gold processing technology that can use in Anggai Village and Air Mangga Village.

Conclusion

The socio-economic baseline can be summarized that miners from Anggai Village and Air Mangga Village are in productive age, with most of the respondents are male, head of a family, immigrant and relatively low average on education level with average income from mining activity relatively low with income <Rp.2,500,000, with most of the respondents' main livelihood being miners in ASGM and having a mining group.

The calculation of cost, income and profit from the amalgamation method is profitable, with an average profit of 1 ton of gold ore is Rp.5,251,380, - with a BC ratio is 3.695 (1 feasible). The miners need alternative gold processing technology with free mercury, namely the cyanidation method. The cost of the cyanidation process is more expensive than that of amalgamation, although cyanidation is, in most cases, more profitable. The gold production is estimated at 38-42 kg per annum. On the other hand, based on information received from the UNDP Field Facilitator, total gold production in Anggai Village and Air Mangga Village is estimated at 38-60 kg per annum. So, with the forecasting that the gold price in next future will rise, it can make increasing income for the miners in Anggai and Air Mangga Villages.

Related the increase in income can make in line with increasing education level and create work and profession for the original residents in Obi Islands. On the other hand, gold processing technology, free mercury, and ergonomics can encourage more female miners to participate in ASGM. Gold processing during this research used mercury to separate the gold from the mud, which did not lead to the worst disaster in the surrounding environment. Thus, agricultural activities are still sustainable to hold. ASGM supported agriculture sustainability from the economic aspect. However. The impact on the environment of this gold mining activity should be resolved by new technologies that are friendly toward nature, such as phytoremediation with many indigenous plant species (Suhartini and Abubakar, 2017).

Gold mining plays a crucial role in employment production, foreign exchange generation, and overall economic activity. Even though mining activities were paralyzed due to the COVID-19 pandemic, gold mining is still evident today. The environmental and health contamination problems caused by mercury are some of the biggest challenges for the sector and the authorities. According to several interviews with local miners, they state that they use mercury to recover the gold extracted from the rivers. Strict measures are needed to prevent and control environmental contamination and quality in general as strategies to manage and guarantee a balance between mining activities and the health of workers and residents of the sector. New ways of working and understanding the needs and requirements of the workers and citizens of the study area are required (Mestanza-Ramón et al., 2022).

The findings of this study indicate that, when taking these measures alone, efforts to mitigate mercury use and emissions following the Minamata Convention on Mercury generate different risks, which, in effect, jeopardize sustainability in ASGM. Comprehensive mercury mitigation strategies which also consider these unintended consequences should include in the action plans adopted by policymakers at the national level (Kosai et al., 2023).

There are many solutions for the environmental, health, technical, and socio-economic problems associated with ASGM. However, a realistic approach should consider improving miners' education level, creating government programs to provide technical assistance in the field, simplifying administrative procedures, and ensuring adequate measures for enforcement (Sousa et al., 2011).

Acknowledgements

This paper is fully supported by the GOLD-ISMIA Project under collaboration between the Ministry of Environment and Forestry, the National Research and Innovation Agency and the United Nations Development Programme (UNDP) Indonesia. The authors are also immensely grateful to the Global Environment Facility (GEF) for funding the project. This paper would not have been possible without the exceptional support from the consultants and contractors (Yayasan Tambuhak Shinta, PT. LAPI ITB, PACT, TEKMIRA, Badan Geologi) who were working with the GOLD-ISMIA Project.

References

Afandi, Y., Tejowulan, R.S. and Krisnayanti, B.D. 2019. Mercury uptake by *Zea mays* L. grown on an Inceptisol polluted by amalgamation and cyanidation tailings of small-scale gold mining. *Journal of Degraded and Mining Lands Management* 6(3):1821-1828, doi:10.15243/jdmlm.2019.063.1821

Brugger, F. and Zanetti, J. 2020. In my village, everyone uses the tractor: Gold mining, agriculture and social transformation in rural Burkina Faso. *The Extractive Industries and Society* 7(3):940-953, doi:10.1016/j.exis.2020.06.003.

Calys-Tagoe, B.N.L., Clarke, E., Robins, T. and Basu, N. 2017. A comparison of licensed and unlicensed artisanal and small-scale gold miners (ASGM) in terms of socio-demographics, work profiles, and injury rates. *BMC Public Health* 17(1):862, doi:10.1186/s12889-017-4876-5.

Gonçalves, A.O., Marshall, B.G., Kaplan, R.J., Moreno-Chavez, J. and Veiga, M.M. 2017. Evidence of reduced mercury loss and increased use of cyanidation at gold processing centers in southern Ecuador. *Journal of Cleaner Production* 165:836-845, doi:10.1016/j.jclepro.2017.07.097.

Grynberg, R., Kandaswamy, V. and Singogo, F. 2021. The ASGM sector in Africa-A child of misery and desperation? *Development Southern Africa* 39(2):151-164, doi:10.1080/0376835x.2020.1868288.

Investopedia.com. 2022. Feasibility Study Retrieved from https://www.investopedia.com/terms/f/feasibility-study.asp#:~:text=A feasibility study is a venture is likely to succeed.

ITB, P.L. 2020. Gold Ismia Project Introduction of BAT/BEP and Socially and Environmentally Sound ASGM Practices. Jakarta.

ITB, P.L. 2021. ASGM Socio-Economic Baseline Survey Report-Obi Island, South Halmahera, North Maluku. Jakarta.

Komatsu, S., Tanaka, K., Sakakibara, M., Arifin, Y.I., Pateda, S.M. and Manyoe, I.N. 2020. Sociodemographic attributes and dependency on artisanal and small-scale gold mining: the case of rural Gorontalo, Indonesia *IOP Conference Series: Earth and Environmental Science* 589, doi:10.1088/1755-1315/589/1/012020.

Kosai, S., Nakajima, K. and Yamasue, E. 2023. Mercury mitigation and unintended consequences in artisanal and small-scale gold mining. *Resources, Conservation and Recycling* 188, doi:10.1016/ j.resconrec.2022.106708.

Krisnayanti, B.D. 2018. ASGM status in West Nusa Tenggara Province, Indonesia. *Journal of Degraded and Mining Lands Management* 5(2):1077-1084, doi:10.15243/jdmlm.2018.052.1077.

Kyaw, W.T. and Sakakibara, M. 2022. Transdisciplinary communities of practice to resolve health problems in Southeast Asian artisanal and small-scale gold mining communities. *International Journal of Environmental Research and Public Health* 19(9):5422, doi:10.3390/ijerph19095422.

Long, R.N., Renne, E.P. and Basu, N. 2015. Understanding the social context of the ASGM sector in Ghana: A qualitative description of the demographic, health, and nutritional characteristics of a small-scale gold mining community in Ghana. *International Journal of Environmental Research and Public Health* 12(10):12679-12696, doi:10.3390/ijerph121012679.

Marin, T., Seccatore, J., De Tomi, G. and Veiga, M. 2016. Economic feasibility of responsible small-scale gold mining. *Journal of Cleaner Production* 129:531-536, doi:10.1016/j.jclepro.2016.03.161.

Mestanza-Ramón, C., Mora-Silva, D., D'orio, G., Tapia-Segarra, E., Domínguez-Gaibor, I., Fernando, J., Parra, F.E., Velásquez, C.R.C. and Straface, S. 2022. Artisanal and Small-Scale Gold Mining (ASGM): management and socioenvironmental impacts in the Northern Amazon of Ecuador. *Sustainability* 14(11):6854, doi:10.3390/su14116854.

Meutia, A.A., Lumowa, R. and Sakakibara, M. 2022. Indonesian Artisanal and Small-Scale Gold Mining-A Narrative Literature Review. *International Journal of Environmental Research and Public Health* 19(7):3955, doi:10.3390/ijerph19073955.

Prabawa, F.Y., Koestoer, R.H.S. and Sukhyar, R. 2021. Socio-economic feasibility study of community's gold mining in Kertajaya Village, Sukabumi Regency, West Java, Indonesia. *IOP Conference Series: Earth and Environmental Science* 882:1-13, doi:10.1088/1755-1315/882/1/012075.

Queiroz, J., Gasparinetti, P., Bakker, L.B., Lobo, F. and Nagel, G. 2022. Socio-economic cost of dredge boat gold mining in the Tapajós basin, eastern Amazon. *Resources Policy* 79, doi:10.1016/j.resourpol.2022.103102.

Sousa, R., Veiga, M., Van Zyl, D., Telmer, K., Spiegel, S. and Selder, J. 2011. Policies and regulations for Brazil's artisanal gold mining sector: analysis and recommendations. *Journal of Cleaner Production* 19(6-7):742-750, doi:10.1016/j.jclepro.2010.12.001.

Steckling, N., Boese-O'Reilly, S., Gradel, C., Gutschmidt, K., Shinee, E., Altangerel, E., . . . Hornberg, C. 2011. Mercury exposure in female artisanal small-scale gold miners (ASGM) in Mongolia: An analysis of human biomonitoring (HBM) data from 2008. *Science of The Total Environment* 409(5):994-1000, doi:10.1016/j.scitotenv.2010.11.029.

Suhartini, S. and Abubakar, A. 2017. Socio-economic impacts and policy of artisanal small-scale gold mining in relation to sustainable agriculture: a case study at Sekotong of West Lombok. *Journal of Degraded and Mining Lands Management* 4(3):789-796, doi:10.15243/jdmlm.2017.043.789.

Taux, K., Kraus, T. and Kaifie, A. 2022. Mercury exposure and its health effects in workers in the artisanal and small-scale gold mining (ASGM), Sector-A Systematic Review. *International Journal of Environmental Research and Public Health* 19(4), doi:10.3390/ijerph19042081.

UNEP (United Nations Environment Programme). 2013. Global Mercury Assessment 2013: Sources, emissions, releases, and environmental transport. https://wedocs.unep.org/20.500.11822/7984.

UNITAR (United Nations Institute for Training and Research). 2018. Socio-economic ASGM Research Methodology. UNITAR, Geneva, https://unitar.org/sites/default/files/media/file/final_socio-economic_methodology.pdf.

Vergara-Murillo, F., Gonzalez-Ospino, S., Cepeda-Ortega, N., Pomares-Herrera, F. and Johnson-Restrepo, B. 2022. Adverse health effects and mercury exposure in a Colombian artisanal and small-scale gold mining community. *Toxics* 10(12), doi:10.3390/toxics10120723.

Wilson, M.L., Renne, E., Roncoli, C., Agyei-Baffour, P. and Tenkorang, E.Y. 2015. Integrated assessment of artisanal and small-scale gold mining in Ghana - Part 3: Social Sciences and Economics. *International Journal of Environmental Research and Public Health* 12(7):8133-8156, doi:10.3390/ijerph120708133.