S E R V I R E
Jurnal Penelitian dan Pengabdian
Vol. 6, No. 2 (2026): 288-300
DOI: 10.46362/servire.v6i2.320

Penyuluhan Masyarakat tentang Dampak Penggunaan Merkuri terhadap Lingkungan dan Kesehatan dalam Pengolahan Emas Tradisional di Kabupaten Sumbawa, Indonesia

Community Outreach on the Environmental and Health Impacts of Mercury Use in Traditional Gold Processing in Sumbawa Regency, Indonesia

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Submitted: 9 August 2025 I Revision: 16 February 2026 I Accepted: 11 March 2026 I Published: 17 November 2026

Citation (APA Style):
Retongga, N., Suci, F.R.Z., Nelvi, A., Suhernomo, S., Handayani, S., Kadji, R., Fitri, Y., Wulandari, M.N., Putrawiyanta, I.P., Himawan, B., Agustin, F., Nafisah, L.A. (2026). Community Outreach on the Environmental and Health Impacts of Mercury Use in Traditional Gold Processing in Sumbawa Regency, Indonesia. *SERVIRE: Jurnal Pengabdian Kepada Masyarakat*, *6*(2): 288-300. https://doi.org/10.46362/servire.v6i2.320.

Abstract: *Artisanal and small-scale gold mining is a major source of mercury pollution, and workers who process ore through amalgamation face daily mercury exposure. This community service activity aimed to help workers at a traditional gold processing unit in Sumbawa Regency, West Nusa Tenggara, Indonesia, understand mercury's risks to their health and the surrounding environment, and to assess whether this knowledge prompted changes in work practices. Eight workers took part in the activity, which followed three stages: a field survey, an outreach session, and a question-and-answer session, all conducted informally at the processing site. Four months later, we returned to the same unit to repeat the outreach and question-and-answer sessions. Data were collected through direct observation, field notes, and discussions with workers, and the two visits were compared descriptively. After the outreach, workers linked their processing waste to environmental pollution and to the shortness of breath and itching they reported. However, their practices remained unchanged: they continued to use mercury, worked without personal protective equipment, and discarded tailings on nearby farmland. Awareness-raising alone was insufficient to change behavior. Future programs should combine outreach with protective equipment, waste containment, mercury-free processing options, and sustained assistance supported by local government.*

Contribution: *This article documents a follow-up visit to the same processing unit four months after the outreach—a step omitted by most community service reports—and finds that workers' improved understanding of mercury hazards did not lead to changes in practice. This finding gives program designers and local governments field-level grounds to pair outreach with protective equipment, waste containment, and mercury-free processing options.*

Keywords: *community outreach; artisanal and small-scale gold mining; mercury; personal protective equipment; knowledge–practice gap; Sumbawa.*

Abstrak: Pertambangan emas skala kecil merupakan salah satu sumber utama pencemaran merkuri. Pekerja yang mengolah bijih melalui amalgamasi juga terpapar merkuri setiap hari. Kegiatan pengabdian kepada masyarakat ini bertujuan membantu pekerja di sebuah unit pengolahan emas tradisional di Kabupaten Sumbawa, Nusa Tenggara Barat, Indonesia, memahami dampak merkuri terhadap kesehatan dan lingkungan sekitar, sekaligus menilai apakah pemahaman tersebut mengubah cara mereka bekerja. Kegiatan ini melibatkan delapan pekerja dan berlangsung dalam tiga tahap: survei lapangan, penyuluhan, dan tanya jawab. Seluruh tahap dilakukan secara informal di lokasi pengolahan. Empat bulan kemudian, tim kembali ke lokasi yang sama untuk mengulang penyuluhan dan sesi tanya jawab dalam kunjungan tindak lanjut. Data dikumpulkan melalui pengamatan langsung, catatan lapangan, dan diskusi dengan para pekerja. Hasil dari kedua kunjungan kemudian dibandingkan secara deskriptif. Setelah penyuluhan, para pekerja mampu mengaitkan limbah pengolahan dengan pencemaran lingkungan serta keluhan sesak napas dan gatal-gatal yang mereka alami. Namun, praktik kerja mereka tidak berubah: merkuri tetap digunakan, pekerja tidak memakai alat pelindung diri, dan tailing masih dibuang ke lahan pertanian di sekitar lokasi. Peningkatan kesadaran saja ternyata belum cukup untuk mengubah perilaku. Program berikutnya perlu memadukan penyuluhan dengan penyediaan alat pelindung diri, penampungan limbah, pilihan pengolahan tanpa merkuri, serta pendampingan berkelanjutan dengan dukungan pemerintah daerah.

Kontribusi: Artikel ini mendokumentasikan kunjungan ulang ke unit pengolahan yang sama, empat bulan setelah penyuluhan—tahap yang jarang dilaporkan dalam kegiatan pengabdian. Temuan menunjukkan bahwa meningkatnya pemahaman pekerja tentang bahaya merkuri belum diikuti oleh perubahan praktik kerja. Hasil ini memberikan dasar lapangan bagi perancang program dan pemerintah daerah untuk memadukan penyuluhan dengan penyediaan alat pelindung diri, penampungan limbah, dan pilihan pengolahan tanpa merkuri.

Kata Kunci: penyuluhan masyarakat; pertambangan emas skala kecil; merkuri; alat pelindung diri; kesenjangan pengetahuan dan praktik; Sumbawa.

INTRODUCTION

Artisanal and small-scale gold mining (ASGM) supports the livelihoods of millions of people in developing countries, but it is also the world's largest source of human-caused mercury emissions. The *Global Mercury Assessment 2018* estimates that this sector accounts for about 38% of all mercury released into the air by human activity.[1] Miners use mercury because it is inexpensive, readily available, and can be handled by one person without complex equipment.[2] The problem is that mercury does not break down. Once released, it moves from the air into soil and water, then enters the food chain. As a

[1] United Nations Environment Programme, *Global Mercury Assessment 2018* (Geneva: UN Environment Programme, Chemicals and Health Branch, 2019).

[2] Louisa J. Esdaile and Justin M. Chalker, "The Mercury Problem in Artisanal and Small-Scale Gold Mining," *Chemistry – A European Journal* 24, no. 27 (2018): 6905–6916, https://doi.org/10.1002/chem.201704840.

result, the health burden also affects residents who are not involved in mining.[3]

Indonesia has extensive ASGM activity, with Sumbawa Island in West Nusa Tenggara Province as one of its centers.[4] In Sumbawa Regency, local people mine and process gold ore using simple equipment and relying on family labor and mutual help; most work without a People's Mining Permit (*Izin Pertambangan Rakyat*, IPR). They grind the ore with mercury in small ball mills, locally called *gelondong*, until an amalgam forms, then burn the amalgam to separate the gold. Around 25–30% of the mercury used is lost to the environment.[5] A study in Lantung District, Sumbawa Regency, found that each processing run used 150–250 mL of mercury and that concentrations in wastewater, river water, and groundwater near the sites exceeded quality standards.[6]

The Indonesian government ratified the Minamata Convention through Law No. 11 of 2017[7] and made eliminating mercury use in the ASGM sector a target of the National Action Plan under Presidential Regulation No. 21 of 2019.[8] Yet a wide gap remains between policy and conditions at processing sites. Although mercury safety outreach has taken place in many regions, community service reports usually stop once the information has been delivered. Teams rarely return to the same site to check whether workers have changed their practices. Experience in Ghana and several other countries shows that workers may continue using mercury even when they understand its dangers.[9]

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[3] Nadine Steckling et al., "Global Burden of Disease of Mercury Used in Artisanal Small-Scale Gold Mining," *Annals of Global Health* 83, no. 2 (2017): 234–247, https://doi.org/10.1016/j.aogh.2016.12.005; Kristin Sippl, "Private and Civil Society Governors of Mercury Pollution from Artisanal and Small-Scale Gold Mining: A Network Analytic Approach," *The Extractive Industries and Society* 2, no. 2 (2015): 198–208, https://doi.org/10.1016/j.exis.2015.01.008.

[4] Baiq Dewi Krisnayanti, "ASGM Status in West Nusa Tenggara Province, Indonesia," *Journal of Degraded and Mining Lands Management* 5, no. 2 (2018): 1077–1084, https://doi.org/10.15243/jdmlm.2018.052.1077.

[5] Marcello M. Veiga et al., "Mill Leaching: A Viable Substitute for Mercury Amalgamation in the Artisanal Gold Mining Sector?," *Journal of Cleaner Production* 17, no. 15 (2009): 1373–1381, https://doi.org/10.1016/j.jclepro.2009.03.012.

[6] Kevin Philips Barakati, Tjahyo Nugroho Adji, and Noorhadi Rahardjo, "Status of Groundwater and River Water Quality around the Location of Illegal Gold Mining Activities in Lantung District, Sumbawa," *Journal of Degraded and Mining Lands Management* 10, no. 3 (2023): 4433, https://doi.org/10.15243/jdmlm.2023.103.4433.

[7] Republic of Indonesia, *Undang-Undang Nomor 11 Tahun 2017 tentang Pengesahan Minamata Convention on Mercury (Konvensi Minamata mengenai Merkuri)* (Jakarta, 2017).

[8] Republic of Indonesia, *Peraturan Presiden Nomor 21 Tahun 2019 tentang Rencana Aksi Nasional Pengurangan dan Penghapusan Merkuri* (Jakarta, 2019).

[9] Gavin Hilson, Christopher J. Hilson, and Sandra Pardie, "Improving Awareness of Mercury Pollution in Small-Scale Gold Mining Communities: Challenges and Ways Forward in Rural Ghana,"

This community service activity addressed that gap. The team visited a traditional gold processing unit in Sumbawa Regency with two aims: to help workers understand the health and environmental dangers of mercury and, during a follow-up visit, to assess whether that understanding led to changes in work practices. The expected changes were simple and directly observable: workers would begin wearing personal protective equipment (PPE) and stop discarding processing waste carelessly.

LITERATURE REVIEW

The health risks of mercury in ASGM are well documented. Mercury vapor inhaled when amalgam is burned is absorbed almost completely through the lungs before accumulating in the kidneys and central nervous system. Tremors, memory impairment, and reduced kidney function have been repeatedly reported in mining communities.[10] Examinations of residents in an Indonesian ASGM area also found signs of chronic mercury intoxication, including among those living near—but not at—the processing sites.[11] Children and pregnant women are most vulnerable, as mercury disrupts neurological development from the prenatal period onward.[12]

This activity is read through the gap between knowledge and practice described in studies of environmental behavior. Kollmuss and Agyeman show that knowing about an environmental problem does not, by itself, lead people to act; economic considerations, established habits, and the availability of alternatives often carry more weight.[13] Work on ASGM points the same way. In rural Ghana, awareness programs on mercury pollution

Environmental Research 103, no. 2 (2007): 275–287, https://doi.org/10.1016/j.envres.2006.09.010; Marcello M. Veiga and Omotayo Fadina, "A Review of the Failed Attempts to Curb Mercury Use at Artisanal Gold Mines and a Proposed Solution," *The Extractive Industries and Society* 7, no. 3 (2020): 1135–1146, https://doi.org/10.1016/j.exis.2020.06.023.

[10] Herman Gibb and Keri Grace O'Leary, "Mercury Exposure and Health Impacts among Individuals in the Artisanal and Small-Scale Gold Mining Community: A Comprehensive Review," *Environmental Health Perspectives* 122, no. 7 (2014): 667–672, https://doi.org/10.1289/ehp.1307864; Jung-Duck Park and Wei Zheng, "Human Exposure and Health Effects of Inorganic and Elemental Mercury," *Journal of Preventive Medicine and Public Health* 45, no. 6 (2012): 344–352, https://doi.org/10.3961/jpmph.2012.45.6.344.

[11] Stephan Bose-O'Reilly et al., "A Preliminary Study on Health Effects in Villagers Exposed to Mercury in a Small-Scale Artisanal Gold Mining Area in Indonesia," *Environmental Research* 149 (2016): 274–281, https://doi.org/10.1016/j.envres.2016.04.007.

[12] Stephan Bose-O'Reilly et al., "Mercury Exposure and Children's Health," *Current Problems in Pediatric and Adolescent Health Care* 40, no. 8 (2010): 186–215, https://doi.org/10.1016/j.cppeds.2010.07.002.

[13] Anja Kollmuss and Julian Agyeman, "Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to Pro-Environmental Behavior?," *Environmental Education Research* 8, no. 3 (2002): 239–260, https://doi.org/10.1080/13504620220145401.

fell short because they paid little attention to the livelihood pressures miners face,[14] and a review of several decades of training and campaigns concluded that mercury use changes little unless miners are offered a processing method that is equally profitable.[15] Where change did occur, as in one Philippine community that replaced mercury with the gravity-borax method, a local organization had supported miners over a long period.[16] For this reason, the follow-up visit in the present activity recorded knowledge and practice separately and did not treat one as evidence of the other.

METHOD

Location, Time, and Participants

The activity was conducted at a traditional gold-processing unit in Sumbawa Regency, West Nusa Tenggara Province. Participants included the unit's eight workers, who operate the ball mills and perform amalgamation each day. The site was selected because it still uses mercury for processing and is located near homes, water sources, and community farmland. The implementing team comprised lecturers from several universities with programs in mining, environmental, and industrial engineering, supported by students.

Design and Stages of the Activity

The activity followed an educational, participatory approach conducted directly at the workplace in three consecutive stages: a field survey, an outreach session, and a question-and-answer session (Figure 1). The outreach and question-and-answer sessions were held twice. The first meeting delivered the material; the second, held four months later, assessed whether participants had understood and applied it.

During the field survey, the team tracked the process from ore grinding through waste disposal. They documented the equipment used, how workers handled mercury, and whether they wore PPE. These observations shaped the outreach materials, ensuring the examples reflected workers' own jobs.

[14] Hilson, Hilson, and Pardie, "Improving Awareness of Mercury Pollution."
[15] Veiga and Fadina, "Review of the Failed Attempts."
[16] Rasmus Køster-Rasmussen et al., "Mercury Pollution from Small-Scale Gold Mining Can Be Stopped by Implementing the Gravity-Borax Method – A Two-Year Follow-Up Study from Two Mining Communities in the Philippines," *New Solutions: A Journal of Environmental and Occupational Health Policy* 25, no. 4 (2016): 567–587, https://doi.org/10.1177/1048291115607929.

Figure 1. Stages of the Community Service Activity.



The outreach took place at the processing site, without a classroom or formal program. This informal format meant workers could stay on the job and speak more freely. The material covered how mercury enters the body; the symptoms and consequences of long-term exposure; how mercury waste moves through soil and water; proper PPE use; and ways to contain waste and prevent its direct release into the environment. Immediately after the presentation, a question-and-answer session invited workers to describe their work habits and any complaints they had experienced.

Data Collection and Analysis

The team collected data through direct observation, field notes, worker discussions, and photographs. At each visit, the team observed four aspects: mercury use, PPE use, workers' reported health complaints, and waste disposal. Notes from the two visits were then compared descriptively and qualitatively to identify changes. The activity did not use pre- and post-test questionnaires or measure mercury concentrations, so findings are based on observations and workers' accounts. Workers at the processing unit consented to participate and be photographed.

RESULT

Condition of the Processing Unit

The processing unit is located on open ground and consists of a row of ball mills powered by a diesel engine. Workers load crushed ore, water, and mercury into the mills and rotate them, then separate the amalgam by hand. Throughout the process, workers wore no gloves, masks, or other protective gear; some wore sleeveless shirts and sandals. They dumped processing residues and tailings sludge on community farmland or directly onto the ground.

The Outreach and Question-and-Answer Sessions

The first outreach session went smoothly. The workers followed the presentation from beside their equipment, and the informal atmosphere encouraged them to ask questions and discuss their work (Figure 2a and 2b). Most questions focused on how gold could be processed or refined without mercury.

Figure 2a. The Team with Workers at the Gold Processing Site after the Outreach and Question-and-Answer Session (Left and Center). Figure 2b. The Team with Workers at the Gold Processing Site after the Outreach and Question-and-Answer Session (Right).



Changes after the Outreach

The second visit revealed a situation different from what had been hoped for. Workers were still processing gold with mercury and working without PPE. During the question-and-answer session, they reported, as they had during the first visit, often experiencing shortness of breath and itching. They also acknowledged that their processing activity pollutes the surrounding environment because they dispose of waste improperly. Table 1 summarises conditions at both visits.

Table 1. Conditions Observed at the First and Second Visits.

Aspect observed	First visit	Second visit
Mercury use	Used in the amalgamation process	Still used
PPE use	Not worn	Still not worn
Health complaints	Workers reported frequent shortness of breath and itching	Unchanged: workers reported frequent shortness of breath and itching
Waste disposal	Discarded on community farmland or directly onto the ground	Unchanged; workers acknowledged that their disposal practice pollutes the environment
Understanding of the dangers of mercury	Material delivered for the first time	Workers could link their work to pollution and to the complaints they experience

Two things stand out from this comparison. Knowledge improved: workers now independently connected processing waste with pollution, which was the central message of the outreach material. Practice, however, remained unchanged. One outreach session and a single follow-up visit were enough to build understanding, but not to change how the work is done.

DISCUSSION

Findings and Context

The main finding of this activity is the gap between what workers know and what they do. This gap has long been recognized in studies of environmental behavior: knowledge is only one of many factors that shape action, and its influence is often outweighed by economic considerations, habits, and available alternatives.[17] For workers in Sumbawa, mercury is the fastest way to turn ore into cash on the same day.

Comparison with Previous Research

Hilson et al. found a similar pattern in Ghana, where awareness programs repeatedly failed because they did not account for the livelihood pressures miners face.[18] Veiga and Fadina went further, concluding that decades of training and campaigns have done little to reduce mercury use when miners are not offered another processing method that is equally profitable.[19] The questions raised by workers in Sumbawa point in the same direction: they asked for a way to process gold without mercury.

The workers' reported shortness of breath and itching align with the exposure routes they face daily. Inhaling high concentrations of mercury vapor irritates the respiratory tract, while direct contact with mercury or processing sludge can cause skin reactions.[20] In a review of dozens of studies on ASGM communities, Gibb and O'Leary identified neurological and kidney disorders as the most common long-term effects;[21] a similar pattern was found among residents of an ASGM area in Indonesia.[22] However, the complaints reported in this activity are based solely on the workers' own accounts.

[17] Kollmuss and Agyeman, "Mind the Gap."
[18] Hilson, Hilson, and Pardie, "Improving Awareness of Mercury Pollution."
[19] Veiga and Fadina, "Review of the Failed Attempts."
[20] Park and Zheng, "Human Exposure and Health Effects."
[21] Gibb and O'Leary, "Mercury Exposure and Health Impacts."
[22] Bose-O'Reilly et al., "Preliminary Study on Health Effects."

Without clinical examinations and measurements of mercury in hair or urine, researchers cannot confirm them as mercury-related effects, since dust from ore grinding and exhaust from the site's diesel engine can cause the same symptoms.

What workers said about waste points to a problem that extends far beyond the processing unit. Amalgamation tailings still contain mercury. When discarded on land or in drainage channels, the mercury can be carried into rivers and seep into groundwater. In water, some of it is converted into methylmercury, which accumulates in fish and can reach the tables of people living far from the mining site.[23] Data from Lantung District show that this is already occurring in Sumbawa Regency: river water and groundwater near processing sites are classified as lightly to moderately polluted.[24] Declines in water and soil quality around small-scale gold mines have also been reported elsewhere in Indonesia.[25] At the unit visited, tailings were discarded on community farmland, placing crops and nearby water sources directly at risk of contamination.

Theoretical and Practical Implications

For those who design community service programs, these results suggest treating outreach as a first step. Programs that have successfully reduced mercury use generally combine education with technology workers can try immediately. A retort, for example, recaptures mercury vapor when amalgam is burned and offers an inexpensive interim measure. In one Philippine community, the gravity-borax method completely replaced mercury, but it was rarely adopted in another; the difference was a local community organization that supported miners over time.[26] Institutional factors matter just as much. When processing occurs without a permit, workers are hard to reach with technical guidance and have little reason to invest in safer equipment. For this reason, the designation of people's mining areas and the issuing of IPR need to be accelerated alongside field assistance.[27] The mercury elimination target in Presidential Regulation

[23] United Nations Environment Programme, *Global Mercury Assessment 2018*.

[24] Barakati, Adji, and Rahardjo, "Status of Groundwater and River Water Quality."

[25] U. N. Hasanah, "Analisis Dampak Kegiatan Pertambangan Emas terhadap Lingkungan Fisik di Desa Paningkaban Kecamatan Gumelar Kabupaten Banyumas Tahun 2021," *Indonesian Journal of Environment and Disaster* 1, no. 1 (2022): 18–23.

[26] Køster-Rasmussen et al., "Mercury Pollution from Small-Scale Gold Mining."

[27] Samuel J. Spiegel et al., "Phasing Out Mercury? Ecological Economics and Indonesia's Small-Scale Gold Mining Sector," *Ecological Economics* 144 (2018): 1–11, https://doi.org/10.1016/j.ecolecon.2017.07.025.

No. 21 of 2019 can be met only if both efforts reach the level of the individual processing unit.[28]

Limitations

This activity has several limitations. It covered only one processing unit and eight workers, so the results cannot be generalized to Sumbawa Regency as a whole. Changes in knowledge were assessed through discussion rather than pre- and post-test instruments, and the four-month interval between visits was relatively short for behavioral change. Follow-up activities should involve more processing units, use measurable assessment instruments, include health examinations and mercury-concentration measurements, and test retorts or mercury-free processing methods in collaboration with workers.

CONCLUSION

Informal workplace outreach helped traditional gold-processing workers in Sumbawa Regency understand the connection between mercury, pollution, and the health complaints they experience. However, this understanding has not yet changed their practices. At a follow-up visit four months later, workers still used mercury, worked without PPE, and disposed of waste in ways they acknowledged pollute the environment.

This experience shows that outreach alone cannot reduce mercury use in artisanal gold mining. Future community service programs should provide sustained assistance, including PPE, waste containment facilities, and safer processing technology for workers to test. Local governments are expected to support these efforts by accelerating the legalization of artisanal mining, offering technical guidance, and monitoring workers' health and water quality around processing sites.

Acknowledgments: We thank the students and lecturers of the Mining Engineering Study Program, Padang College of Industrial Technology, and the Mining Engineering Study Program, Sumbawa University of Technology, for their support, input, and collaboration in this community service activity, which made this article possible.

Competing Interests: The authors declare that they have no financial or personal relationships that may have inappropriately influenced the research, analysis, or writing of this article.

Ethical Considerations: This activity was a community outreach program that involved no clinical intervention, biological sampling, or collection of personal health records, so formal ethical clearance was

[28] Republic of Indonesia, *Peraturan Presiden Nomor 21 Tahun 2019*.

not required by the authors' institution. The eight workers were informed of the activity's purpose and gave verbal consent to participate and be photographed. No names or other personal identifiers of the workers are reported.

CRediT authorship contribution statement: Nofrohu Retongga: Conceptualization, Methodology, Investigation, Writing – original draft, Project administration. Fitria Rahmadhani Z. Suci, Afni Nelvi, Suhernomo: Investigation, Data curation. Suci Handayani: Methodology, Validation. Robertho Kadji, Yelli Fitri, Miranti Nur Wulandari, I Putu Putrawiyanta, Ahmad Fithry Arief Lopa, Bayu Himawan: Resources, Visualization, Writing – review and editing. Friska Agustin, Lany Amatun Nafisah, Hisni Rahmi, Muhammad Rus Dodi Alfayed, Emil Salim Kahmi Leka: Validation, Writing – review and editing. All authors read and approved the final manuscript.

Funding Information: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability: The field notes and photographs that support this article are available from the corresponding author upon reasonable request.

AI Use Disclosure: The authors used Claude (Anthropic) to check the conformity of the manuscript with the journal template. The authors reviewed all output and remain responsible for the accuracy, originality, integrity, and ethical compliance of the article.

Disclaimer: The views and interpretations expressed are those of the authors and do not necessarily reflect those of their affiliated institutions, the editors, or the publisher.

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