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An overview of remediation technology for mercury-contaminated sediment in Sekotong Sub District, Lombok, Indonesia

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Abstract. The gold mining sector in Indonesia consists of large-scale gold mining, medium-scale gold mining, and small scale gold mining. Small scale miners generally use mercury amalgamation method to extract gold as it is considered as the most efficient method and requires only a small investment. The utilization of mercury might affect environmental quality and human health. This study is aimed to evaluate the possible remediation technology for mercury-contaminated sediment. A case study from Sekotong Sub District was carried out due to the operation of small scale mining in this area. The qualitative method was used by using a literature review approach. Various technologies of mercury remediation were explored and compared. The results indicated that there were 12 available technologies associated with mercury sediment handling. Those technologies include dredging, in-situ thermal desorption, capping, activated carbon, solidification, and nanotechnology. The appropriate technology is determined by some aspects, including mercury intensity, technology effectivity, and cost. In addition, the application of those technologies requires a social license to operate not only from the community but also from the government as a regulator.

10 Introduction

Mercury is the only metal in the form of liquid under the room temperature (20°C) in nature. Most mercury is found in nature in a combined form with other elements such as cinnabar (HgS) or as a trace component of many minerals. Mercury is used in various forms and purposes to support human life, including in artisanal and small-scale gold mining (ASGM). [1]. Mercury (Hg) has been recognized as one of the most hazardous heavy metals due to its high volatility, persistence, and bioaccumulation in human beings and natural biota [2].

Because of its biomagnifies in the food chain and its toxicity, mercury generates a great deal of concern as a primary heavy metal pollutant. Mercury poisoning can be through inhalation, digestion, or absorption through the skin. Methyl mercury attacks the nerves of the brain so that it can cause vision and hearing problems. [3]. Direct (point source) Hg contamination is usually generated by abandoned Hg mines, gold mining activities, and ore refining. Every year about a thousand metric tons of mercury has been released from ASGM all around the world to the environment which is 65 % release to the hydrosphere. [4].

The gold mining sector in Indonesia consists of large-scale gold mining, medium-scale gold mining and small-scale gold mining. In the field of mining, only small-scale gold mining that used elemental mercury for refining gold through the amalgamation process. The amalgamation process requires only



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a low investment and is an easy technique to do, by mixing mercury with the gold ore, then gold will be bound with mercury and form amalgam. Besides, there is always mercury lost to the environment through wastewater disposal from amalgamation treatment process [5]. In Sekotong Sub District, West Lombok District, West Nusa Tenggara Province, artisanal and small-scale gold mining (ASGM) started in 2008. The gold amalgamation waste flows into a tailing pond or directly flows into the river. Rahmawati and Hadi showed that in 2009 mercury concentration in gastropods, some estuaries in Sekotong ranged between <0.0057 – 0.56 mg/kg [6] and Junaidi et al. research indicates that in 2016, mercury concentration in Pilsbryconcha (shell) is 596 ppb, above the WHO maximum permissible limit for fish for human consumption 500 ppb [7]. The habitat for this organism is sediment. This means that mercury contamination has reached the estuary where the shell is found.

Mercury contamination will be a threat to tourism in Sekotong. Sekotong is surrounded by beautiful white sandy beaches such as Bangko-Bangko beach that has been known as one of the most famous surfing spots and a lot of small islands (Gili) such as Gili Nanggu, Gili Sudak, Gili Tangkong, Gili Kedis, Gili Laya, Gili Gede, and Gili Rengit. Several activities highlighted for tourists in these small islands including snorkeling, diving, sunset, and sunrise viewing activity. Sekotong bay is an important fishing area, as well.

Mercury, like many other heavy metals eventually buried under soils and sediments for decades (such as in Kastela Bay, Croatia, mercury buried in sediment for almost 40 years from now and still remain [8]), difficult to be degraded in the environment and therefore, remediation technologies are needed to reduce/remove mercury from the environment [3], [9]. The objective of this study is to evaluate the possible remediation technology for mercury-contaminated sediment. A case study from Sekotong Sub District was conducted due to the operation of small scale mining in this area.

2. Method

The method of this paper is a qualitative method by using a literature review approach. Various technologies of mercury remediation were explored and compared. The analysis, including the advantage and disadvantages of mercury remediation technologies, were conducted descriptively, and it showed in the table.

3. Result and Discussion

The Government of Indonesia announced its plan to phase out mercury use in ASGM entirely in 2017 by ratified the Minamata Convention on Mercury into Law No. 11 of 2017. The Minamata convention regulates the sources of mercury supply and trade; mercury management in ASGM; controlling emissions and release of mercury into the air, water, and soil; management of mercury waste and mercury-contaminated land. ASGM must take a step to reduce the use of mercury and mercury compounds, as well as emissions and releases mercury from amalgamation process. Mercury use and pollution in Indonesia's ASGM sector has been increasing significantly over the past two decades. Therefore, remediation technologies are needed to reduce/remove mercury from the environment [10]. Various Mercury remediation technologies in sediment showed in Table 1.

Tabel 1. Various mercury remediation technologies [1] [3] [5] [9] [11] [12]

Technology	Descriptions	Advantage	Disadvantage
Dredging	Excavating contaminated sediment from the bottom of the water column by using hydraulic or mechanical techniques.	Fixing the aquatic environment by removing contaminated sediment	High cost, disturbing of aesthetic and aquatic biota, decreasing the quality and ecosystem function, remobilization of contaminated sediments, disrupt natural recovery process

Technology		Descriptions	Advantage	Disadvantage
In situ thermal desorption		Mercury is removed from the contaminated sites in the form of vapor by heat treatment and then collected and treated	Could be used to remove mercury from any depth	High cost, the potential risk from mercury vapor
Capping		Placing material to cover the contaminated sediment. Caps may be constructed of activated carbon, sand, gravel, iron sulfide minerals	A lower cost than dredging, minimize the environmental impact by preventing contaminant's mobilization	Need long-term in maintenance and monitoring to ensure it protective
Dredging and capping		Combination of dredging followed by capping	The contamination removed from the aquatic environment	Need long-term monitoring to ensure cap integrity
Monitored recovery	natural	Relies on natural process to protect the environment	Comprehensive and cost-effective, being the least disruptive option for an ecosystem	Takes more extended time based on natural processes to reduce contamination
Enhanced recovery	natural	Accelerating the process of physical isolation, which is continued by natural sediment deposition	Increase the natural sedimentation rate; low implementation efforts results in lower costs	Takes more extended time than active remediation
Activated carbon		Activated carbon is added to the sediment to increase the surface area to bind mercury and reduce bioavailable methyl mercury	Highly remove mercury from sediments	High cost
Electrokinetics		A low-intensity direct current (using electrodes) is applied to remove the contaminant from the sediment.	No excavation required; can be conducted in-situ and ex-situ, little disturbance to contaminated site, cost-effective	May need complexing agents to mobilize mercury
Solidification		A process that involves mixing contaminant with binding agents to reduce the leaching of	Mature and commercially available, useful in mobilizing	Use chemical reagent that may cause problem themselves

Technology	Descriptions	Advantage	Disadvantage
	contaminant both physically and chemically	contaminants	
Vitrification	Using electricity to heat and destroy organic compound and immobilize inorganic contaminant on sediment then converts waste into a glass or crystalline material	Reduce/eliminate contaminant's mobilization, could be implemented together with other technologies,	The process requires energy-intensive and high temperature, the exit gas must be treated before disposal, high cost,
Phytoremediation	A bioremediation process that uses the various plant to adsorb mercury/contaminant from sediment	environmental-friendly, cost-effective, can be implemented in-situ and ex-situ in large scale operation, the plant can be easily monitored	Harvested plant biomass need offsite treatment, slower process of remediation,
Nanotechnology	the nanomaterial is used to bind mercury by adsorption or ion exchange	Use non-toxic chemicals, cost-effective	Need more research to apply this technology to the real site.

Removal technologies are preferable because the mercury could be removed permanently, but the technology is high cost. Remediation of Minamata Bay in Japan using the dredging technology at the cost of around 500 million dollars and succeeded in removing 1.5 million tons of contaminated sediment. After thirteen years, the analysis showed that the concentration of mercury in sediment and fish met the established criteria [11]. In-situ thermal desorption removes elemental mercury effectively even though it is classified as a high technology also. Hamilton harbor, Canada, implemented capping technology over mercury-contaminated sediment and other heavy metals. After a year, the mercury concentration in the cap 10,000 times higher than contaminated sediment below the cap [4]. Phytoextraction is one of the phytoremediation methods. The phytoextraction process is excellent for handling media that is polluted by heavy metals. Nanoparticles have a tiny surface area to volume ratio which means that only a small amount is needed to remove relatively large pollutants. Nanotechnology shows the potential for cost-effective cleaning of polluted soil and sediment in the laboratory scale.

Theoretically, all technologies are possible for mercury handling in sediment in Sekotong. However, the selection of remediation technology depends on Sekotong's specific condition, mercury concentration, and support from the community, so the government should collaborate with all parties. Collaboration between government and researchers/engineers to determine the area to be clean up, determine the appropriate technology, and find safer alternatives to replace mercury as the gold extracting agent, collaboration between government and local community to support the remediation program. The local community could be the supervisor of the program.

The remediation program will give advantage to the community, especially for the local community; it can help them to increase the number of tourists that will come to this place to feel safe. In order, the collaboration with all parties has to sustain. The Government must provide remediation fund because implementing the remediation program is high cost and need multi-years monitoring.

4. Conclusion

Mercury contamination in the environment will be a threaten for tourism in Sekotong; therefore, effective remediation approaches are necessary. Many remediation technologies are possible for mercury handling in sediment in Sekotong. The appropriate technology is determined by some aspects, including mercury intensity, technology effectivity, and cost. In addition, the application of those technologies requires a social license to operate not only from the community but also from the government as a regulator.

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