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Children Development in Artisanal Gold Mining Area at Jendi Village, Selogiri, Wonogiri

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Abstract

Artisanal gold mining (AGM) is an important economic activity in many countries around the world, including Indonesia. Amalgamation is still the most popular method to extract gold for artisanal gold miners. Mercury has been well-known for its potent developmental toxicity. This makes children living in AGM area are vulnerable to hazardous effects of mercury. The AGM at Jendi Village, Selogiri, Wonogiri, Indonesia has been conducted since 1993. The mercury rich tailing discharged directly to surface soil, resulting contamination to its surrounding. Children are exposed to mercury through various routes, i.e. air, water, food and soil, then it will influence their developing nervous system. This study was aimed to assess the development of children living at Jendi Village which is exposed to mercury from AGM activities. As many as 54 children under five were participated in this study, taken from 9 sub-villages at Jendi Village which were then divided into 2 groups, exposed and un-exposed area. Children's hair-Hg analysis was conducted at Water Engineering Laboratory, Toyohashi University of Technology, Japan. Five aspects of development, i.e. : communication, gross motor, fine motor, problem solving and personal-social were assessed using modified Ages and Stages Questionnaires. Result revealed that the average of children's hair-Hg level was 1.09 ppb, ranged from 0.5 to 8.87 ppb. All levels were below the WHO safety limit of 10 ppm above which adverse effects of brain development are likely to occur.

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There were 11.1%, 3.7%, 5.6%, 31.5% and 11.1% of children who were categorized as below cut-off point in communication, gross motor, fine motor, problem solving and personal-social aspect of development, respectively. There were no adverse association between children's hair-Hg level and any aspects of children development. From statistical analysis we could conclude that there were differences in problem solving aspects of children development between exposed and un-exposed area. It means that mercury use in AGM should be discontinued or substantially reduced to give healthier environment for children development.

Keywords: amalgamation; artisanal gold mining; children development; mercury; neurotoxicity.

1. Introduction

In many developing countries, including Indonesia, artisanal gold mining (AGM) has become an important economic activity, as it provides source of livelihood for rural communities [1,2]. This sector apply rudimentary techniques of gold extraction, highly manual processes, hazardous working conditions, and frequently negative human and environmental health impacts. It was estimated that as many as 15 million individuals in developing countries are involved in extracting gold using rudimentary techniques ~10 years ago [3]. However, AGM contributes to the largest intentional use of mercury and causes extreme mercury pollution. Mine operators depend on the metal to amalgamate gold but generally discard it freely into the natural environment [4]. The Global Mercury Assessment by [5] estimated that ASMof gold released ~727 t (metric tonnes) of Hg to the environment per year. This is 37% of the global 1960 t of Hg released annually by anthropogenic sources to the environment [5] (In the text the number of the reference should be given in square bracket. (see example of the article at Procedia)

The main reasons that mercury is so widely used by artisanal gold miners are that mercury is easy to use, available, inexpensive and miners are not aware of, or choose to ignore, the health risks. (Veiga, 2006)[6]. It also ensures a relatively high gold recovery rate (UNEP, 2012)[7]. Between 1 and 2 g of mercury are required to extract 1g of gold, depending on miners' extraction methods and the ore. More mercury is used for ASGM—an estimated 1,400 metric tons in 2011—than for any other use of the metal. The ASGM industry emits an estimated annual average of 1,000 metric tons of inorganic mercury, about one-third of which is thought to go into the air while the rest winds up in piles of mining waste ("tailings"), soils, and waterways [8]. As a consequence, people living and working in small-scale gold mining settlements are exposed to mercury contamination, including children who are vulnerable to environmental contaminants [9].

Mercury is highly toxic, causing damage to the nervous system at even relatively low levels of exposure. It is particularly harmful to the development of fetus and children [9]. They have specific periods in their development when the exposure to a chemical, physical or biological agent may result in adverse health outcomes. Damaged of the nervous system caused by Hg is likely to be permanent. Neurotoxic effects can result from prenatal or early postnatal exposure, through air, water, food and soil on the contaminated area [10]. Transplacental exposure is the most dangerous, as the fetal brain is very sensitive [11].

The effects elicited by mercury depend on the degree of exposure. Even small amounts of mercury affect the

human nervous system and cause muscular tremors, while larger amounts can lead to various neurological disorders such as coordination problems and erithism. Chronic mercury poisoning give rise to inflammation in the gingiva, tunnel vision, and permanent brain damage. Neurologic symptoms for children include mental retardation, seizures, vision and hearing loss, delayed development, language disorders and memory loss [11]. The outcome of developmental neurotoxicity may not be immediately apparent in the infant, but deficits will become evident later on as long-standing or irreversible dysfunctions [12]. Nevertheless, small-scale miners continue to apply mercury carelessly due to a lack of proper alternatives, limited health awareness, and low education [9].

The mercury problem is mainly a man-made problem and therefore can be minimized by implementing efficient measures and programs [10]. Thus, the purpose of this paper is to assess children development in artisanal gold mining area which are exposed by mercury from amalgamation process done by artisanal gold miners at Jendi Village, Wonogiri, Indonesia.

2. Materials and Methods

2.1. Study design

This was an observational study using cross-sectional approach. Collection of biologic samples (i.e. hair) among children under five years old in the community and identification of characteristics of parents such as age, education, occupation and family income.

2.2. Study site

The study was done in an artisanal gold mining community at Jendi Village, Selogiri Sub-district, Wonogiri, Central Java, Indonesia in 2013. The place was selected based on the following criteria : accessibility and cooperation of the community members. Gold mines were started to be explored in 1993, tailing from ball mill operation directly discharged to surface soil. It was estimated that 300 people were engaged in gold mining activities.

2.3. Population and sampling

The sample for this study was drawn from residents living in the 9 sub-villages at Jendi Village around the artisanal gold mining area. Randomized selection of subjects was undertaken from a population in the community. Subjects were included according to the following criteria: mother of children under five years old and living in mining community at least since their children were born.

2.4. Sample selection

We studied 54 children under five years old, living in the area of artisanal gold mining where most of population depends their income in gold mining activity. The objectives and methods of the study were described to respondents. They gave formal consent to participate in the work.

2.5. Hair-Hg analysis

A minimum of 10 mg of hair strands (approximately 2 - 3 cm long) was obtained from the root in the occipital region of each participant. Hair samples were coded and stored in plastic bags until analysis. To measure the mercury concentration, hair samples were washed with detergent and rinsed with water. After that, the samples were dried in an electric oven at 50 °C for 12 hour, and then they were cut in pieces as small as possible. The determination of Hg levels was carried out by the NIC, RA-3, Mercury Analyzer (Japan) at the Laboratory of Water Environment Engineering, Toyohashi University of Technology, Japan. The analytical procedure was validated by analyzing human hair Certified Reference Material (CRM), the NIES CRM No. 13 obtained from the National Institute of Environmental Studies, Environmental Agency of Japan.

2.6. Children development assessment

The modified Ages and Stages Questionnaires for children between 24 - 60 months of age was used to measure children's development. This instrument cover five aspects of development, i.e. communication, gross motor, fine motor, problem solving and personal-social. Data was collected from direct testing, observation and interview with caregiver.

2.7. Statistical analysis

Descriptive statistics were used to characterize the studied population in terms of sociodemographic variabes and hair mercury levels. Exposure was defined by hair mercury concentration. Data were coded and analyzed using the Statistical Package for Social Sciences (SPSS for Windows). Kruskal-Wallis test was used to determine association between hair-Hg levels and each aspect of children development. Kolmogorov-Smimov test was used to assess difference of children development between exposed and unexposed area. The level of statistical significance was set at $p < 0.05$.

3. Results and Discussion

3.1. Description of Research Area

This AGM was located at Jendi Village, Selogiri Sub-district, Wonogiri District, Central Java Province. This village has 163,906 square meters and consists of paddy fields and some hilly area in southern part where the gold ores are mined. The total population is about 7,085 people, consist of 3,616 male and 3,469 female. Most of the inhabitants live as miner and farmer.

The artisanal gold mining activity has been conducted since 1993. This process use simple technique to extract gold from ores and rocks. Mining is done in groups, each consist of about 4-7 people who has different task. Most of miners are local inhabitants. Figure 1 below describes flow process of artisanal gold mining at Jendi Village, Selogiri, Wonogiri, Indonesia.

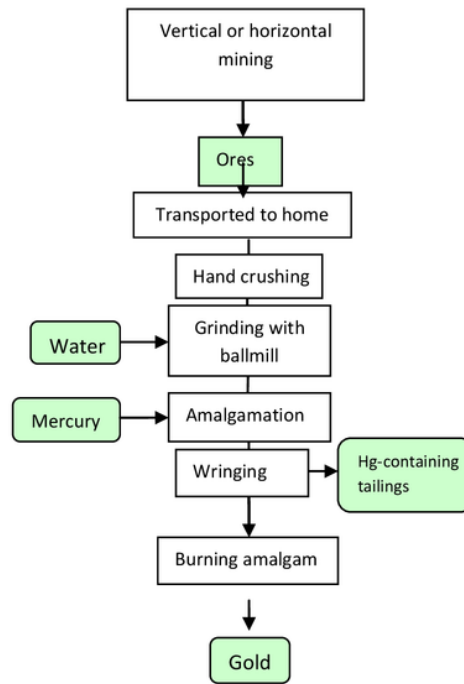


Figure 1: Flow process of artisanal gold mining operation to extract gold at Jendi Village, Wonogiri, Indonesia

Table 1: Characteristics of the study population

Characteristics	Exposed area	Unexposed area	Total
Age of children (months)			
- Min	24	23	23
- Max	61	60	61
- Mean	43,9	43.7	43.7
Gender			
- M	8 (36.4	7 (21.9 %)	15 (27.8%)
- F	14 (63.6%)	25 (78.1%)	39 (72.2%)
Low Birth Weight Status			
- Yes	5 (22.7%)	4 (12.5%)	9 (16.7%)
- No	12 (52.0%)	28 (87.5%)	45 (83.3%)

		(77.3%)		
Maternal age				
- Min	23	21	21	
- Max	45	45	45	
- Mean	33.3	32.3	32.7	
Paternal age				
- Min	28	24	24	
- Max	48	55	55	
- Mean	36.6	37.4	37.1	
Maternal education				
- Lower	11	9 (28.1%)	20 (37.0%)	
- Higher	(50.0%)	23 (71.9%)	34 (63.0%)	
	11			
	(50.0%)			
Paternal Education				
- Lower	12	11	23 (42.6%)	
- Higher	(54.5%)	(34.4%)	31 (57.4%)	
	10	21		
	(45.5%)	(65.6%)		
Maternal Occupation				
- Housewives	16	16	32 (59.3%)	
- Working	(72.7%)	(50.0%)	22(40.7%)	
	6(27.3%)	16(50.0%)		
Paternal Occupation *				
- Miner	17 (77.3%)	5 (15.6%)	22 (40.7%)	
- Non-miner	5(22.7%)	27 (84.4%)	32(59.3%)	
Family income				
- Lower	1 (4.5%)	6 (18.8%)	7 (13.0%)	
- Higher	21(95.5%)	26 (81.2%)	47(87.0%)	

Demographic characteristics of the 54 study subjects are summarized in Table 1. The average age was 43.7 months, range from 23 to 61 months. As many as 22 participants (40.7%) was artisanal gold miners. Only 7 families (13.0%) had monthly income lower than the minimal standard salary for Wonogiri Regency (Rp 830,000).

3.2. Hair mercury level

Table 2 compare mean of children's hair-Hg level between exposed and un-exposed area. The mean hair-Hg concentration was 1.087 ± 1.552 ppb. None of participant had a hair mercury concentration above 10 ppm

which is the World Health Organisation (WHO) safety limit above which adverse effects on brain development are likely to occur (WHO, 1990) [13]. The mean hair-Hg for exposed area (1.441 ppb) was higher than un-exposed area (0.843 ppb). The highest hair-Hg level for exposed area (8.670 ppb) was higher than un-exposed area (5.330 ppb).

Mercury levels in hair generally reflect environmental exposures to methylmercury, though on average about 20% of mercury in hair may be derived from inorganic sources [14]. Generally, hair mercury levels in AGM area are contributed from inhalation of elemental mercury from burning amalgam process to separate gold from mercury. At Jendi Village, location for burning amalgam was centralized at one site, thus not all miners did this activity. This made source of elemental mercury vapor localized at one point.

Table 2: Children's Hair-Hg at artisanal gold mining area, Jendi Village, Wonogiri, Indonesia

Parameter	Total Hair-Hg (ppb)		
	Exposed area	Unexposed area	Total
N	22	32	54
Mean \pm SD	1.4405 \pm 1.9466	0.8434 \pm 1.1837	1.0867 \pm 1.5519
Median	0.7650	0.4400	0.4850
Minimum	0.0500	0.0900	0.0500
Maximum	8.6700	5.3300	8.6700

Our findings provide no evidence for an adverse association of mercury exposure from artisanal gold mining activities on development of children under five years old. Hair-Hg levels as biomarker contaminant of mercury exposure were all in normal range, with the average for exposed area (1.44 ppb) was higher than un-exposed area (0.84 ppb). This result was different with other study done by Bose-O'Reilly and his colleagues [15] in Sulawesi (Indonesia) and Kadoma (Zimbabwe). The median of hair-Hg levels of children living in mercury-contaminated area was 2.31 ppm. Although this value was below the WHO safety limit of 10 ppm, but this level was higher than US EPA (United States Environmental Protection Agency) reference dose of 1 ppm. This level was also lower than concentrations found in children from Korea (0.74 ppm) (Kim *et al*, 2008)[16], US (0.12 ppm) [17] and Amazon, Brasil (11.0 ppm) [18]. The difference of results obtained from this study may be due to some reasons. Although mercury was used intensively at Jendi Village to form amalgam with gold, but the children living there consumed drinking water from safe source (tap water).

The main route of methylmercury exposure is via fish consumption [19], but in this study, fish consumption was relatively low as their menu usually based on land crops. They also consumed crops from other villages where mercury contamination were relatively low. These made mercury exposure via oral route was minimal.

Besides that, since 2012, local government made program to help artisanal miners control their waste from

amalgamation process. Tailings from each ball mill are collected in three sedimentation ponds built at miner's yard near the grinding unit. The sediment then sold to buyer whom recover the mercury contained at the tailings. This program may contribute to decrease mercury emission to soil and ground water.

3.2. Children development assessment

Table 3: Five aspects of children development in exposed and un-exposed area at Jendi Village, Wonogiri, Indonesia

Aspect of development	Stage of development									Sig.
	Below cut-off point			Close to cut-off point			On scheduled point			
	Exposed area	Un-exposed	Total	Exposed area	Un-exposed	Total	Exposed area	Un-exposed	Total	
Communication	6 (100%)	0 (0%)	6 (100%)	4 (28.6%)	10 (71.4%)	14 (100%)	12 (35.3%)	22 (64.7%)	34 (100%)	0.287
Gross motor	1 (50.0%)	1 (50.0%)	2 (100%)	2 (50.0%)	2 (50.0%)	4 (100%)	19 (39.6%)	29 (60.4%)	48 (100%)	1.000
Fine motor	2 (66.7%)	1 (33.3%)	3 (100%)	7 (38.9%)	11 (61.1%)	18 (100%)	13 (39.4%)	20 (60.6%)	33 (100%)	1.000
Problem Solving	13 (76.5%)	4 (23.5%)	17 (100%)	3 (50.0%)	3 (50.0%)	6 (100%)	6 (19.4%)	25 (80.6%)	31 (100%)	0.002*
Personal-social	4 (66.7%)	2 (33.3%)	6 (100%)	7 (53.8%)	6 (46.2%)	13 (100%)	11 (31.4%)	24 (68.6%)	35 (100%)	0.389

Table 3 shows the result of children development assessment in five aspects. There were no difference in communication, gross motor, fine motor and personal-social score between exposed and un-exposed area. Only in problem solving aspect, the Kolmogorov Smirnov test showed significant different between these two groups.

Children are especially vulnerable to environmental health hazards. The reasons are they have greater and longer exposure, and their developing organs have particular susceptibility windows (e.g. during germ-cell development, embryonic and fetal development, ongoing development in childhood)[20]. In this spesific time of window, Hg exposure can affect neurobehavioral functions. Mild exposure may result in delayed symptomp (not observed at birth), such as diffiulty in walking and talking, and persistence of abnormal perinatal reflexes [13, 21].

6 Child development is a dynamic process shaped by a complex interplay between genetic factors and environmental factors, such as antenatal maternal health (including fetal exposure to toxins), in utero conditions, the birth process, nutrition, the economic and social conditions facing the family, and family interpersonal behavior [22]. It is well known that organic and inorganic mercurials cause neurobehavioral changes, mainly during early phases of development, leading to loss of cognitive and motor functions in the childhood [23].

Although the findings of this study failed to demonstrate association between hair-Hg levels and children development, since all hair-Hg levels were below the WHO safety limit, but there were differences of children development who were living in exposed and un-exposed area. To prevent the negative impacts of mercury, miners should replace the existing method with toxic free technique such as borax method, or using magnets and centrifuges [24].

4. Conclusion

The children's hair-Hg levels were in normal range, none exceeded the WHO safety limit. At present background mercury exposure levels from AGM activities, adverse effects on five aspects of children development are not detectable. But from statistical analysis, there was significant different in problem solving aspect of development between children living in exposed and un-exposed area. To prevent the negative impact of mercury exposure to children development, it is necessary to replace the existing amalgamation method with other simple and more environmental friendly technique to reduce and prevent mercury emission to its surrounding environment.

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