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Assessing impact of artisanal and small scale gold mining activities on inhabitants and miners: a case study in Bolaang Mongondow, North Sulawesi Province, Indonesia

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Abstract: Mercury level in scalp hair of inhabitants and gold miners livings at two artisanal and small-scale gold mining (ASGM) sites in Bolaang Mongondow regency of North Sulawesi Province were studied. Totally 50 scalp hairs were collected from Tanoyan, Tobongon and Kotamobagu city, and kept for further analysis. The mercury hair contents were determined using Particle Induced X-ray Emission (PIXE) at Nishina memorial research facility of Iwate Medical University of Japan. Mean levels of mercury in scalp hairs of inhabitants and ASGM workers were around 5 ppm. The highest mercury levels were found at females miners in Tobongon and female teenagers in Tanoyan.

Keywords: mercury; ASGM; Bolaang Mongondow; pollution

1. Introduction

Gold mining activities in Bolaang Mongondow region is regionally known. The historical record showed that there was activities during Dutch colonial era [1]. From 1996 to 2004, Newmont Minahasa Raya (NMR) operated in Bakan of Bolaang Mongondow and produced about 8 kg of Gold per year [2]. Nowadays NMR was replaced by J Resources which are operating in There several Gold mining prospects in Bolaang Mongondow namely: Avocet's North Lanut mine with target deposit capable producing at least of 50,000 ounces gold annually. Gold mineralization in Bakan is estimated has 10.32 tons of gold [3]. Close to each prospects there are ASGM activities by local people, they are known as the Tobongon and Tanoyan ASGM.

Artisanal and Small-scale Gold mining activities are also found along activities of Gold mining companies, and it is regionally known, accepted even though there is no legal standing on the activities yet. There are several locations of ASGM in Bolaang Mongondow namely: Bakan, Modayag, Tanoyan and Tabongan. Local and national publications on the environmental, law issues are available [4–10]. Unfortunately there is no comprehensive international report on subject yet. This study is aimed to provide the comprehensive analysis (ASGM activities, mercury pollution, health assessment and law) on the subject.

Such report is needed as baseline information on the mercury pollution from ASGM activities and its impact to inhabitant for specific region of Bolaang Mongondow. The published scientific infromation will help further related research in the region.

2. Method

Bolaang Mongondow is a region comprises vast area bordering Sulawesi Utara Province and Gorontalo Province. It was formerly known as Bolaang Mongondow Regency, now it is divided into several regencies (Bolaang Mongondow, Bolaang Mongondow Utara, Bolaang Mongondow Selatan, Bolaang Mongondow Timur and Kotamobagu city). Kotamobagu valley is located at higher elevation (about 180 to 130 m above sea level), is surrounded by mountains. Gunung Ambang is a Nature reserve is just about one hour by car from the city [11]. It is a complex of volcanoes at western part of northern arm of Sulawesi [12].

Bolaang Mongondow–Tanoyan

Tanoyan ASGM is located in Bolaang Mongondow Timur regency and about 21 km from Kotamobagu city and can be reached in 35 minutes by car. The ASGM miner's camps are distributed along the Tanoyan river bank. The river is may contaminated by mercury from ASGM activities through direct way.

Figure 1. *The Tanoyan ASGM site showing workshop of trommol in back site and bags of leftover of sediment waste in the foreground.*

Figure 2. The Cyanidation plant in Tobongon, three cylinders left and four cylinders right and pond of mining waste is behind.

Bolaang Mongondow–Tobongon

Tobongon ASGM site is located Bolaang Mongondow Timur regency; it is about 13 km from the Kotamobagu city and can be reached in 22 minutes by car. The Tobongon mining area comprises about 4 km^2. The ore excavation sites are about 2 km along river bank and lies in the Tobongon river banks, which is very steep. Group of miners (5 persons) are working in each camp which are very close to each other (ten meters) along the very narrow river, which strong streams. They were using the only one ore processing site, just 50 meters from the river bank to the north. It is surrounded by houses, kiosks, and a mosque. There are ponds close to the mosque; the ponds were made

using tailing bags. Fish cultivated in the ponds is being consumed by local populations.

Cyanidation plant is found at The Tobongon ASGM site. It consists of seven cylinders of about 3 meters in diameter and 7 meters high. The cynadiation plant receives tailing from Tobongon ASGM and outside.

We visited the ASGM locations during February 2015, where we counducted the following research activities:

- Interview with head of villages, head/representative of ASGM locations, several gold miners and inhabitants.
- Taking scalp hairs of totally 50 gold miners and inhabitants.
- Taking the sediment samples from mining waste and nearby rivers.

The procedure of interview, scalp hair collection and sediment sample collection are explained in detail [2]. The scalp hair samples were brought to Ehime University for preparation and later sent to Iwate Medical University for analysis using PIXE. The facility has been used for to identify the heavy metals in various samples, including human scalp hair[13]. The accuracy and precision of PIXE analysis on mercury concentration in the scalp hair has been discussed elsewhere [14,15].

3. Result and Discussion

The distributions and range of mercury levels in 50 hair samples collected from the three sub districts are summarized in Table 1. The hair mercury concentrations of all participants are more than 1 μg/g, which indicates the toxicity level is already in alert level according to HBM [16].

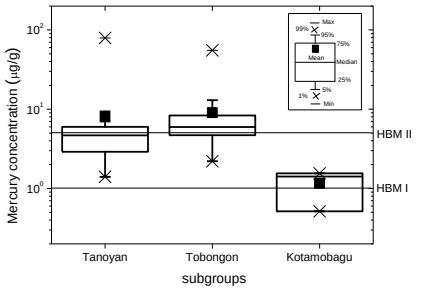
Table 1. Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, Tobongon and Kotambagu.

Residence	*Sex*	*N*	*Hair Mercury Content (μg/g)*		
			Mean ± SD	*Min*	*Max*
Kotamobagu	F	1	*1.6 ± 1.8*	*1.6*	*1.6*
	M	*2*	*0.97 ± 0.60*	*0.50*	*1.4*
	Total	*3*	*1.2± 0.6*	*0.50*	*1.6*
Tanoyan	F	18	*5.0 ± 2.6*	*1.4*	*79.3*
	M	*7*	*4.3 ± 1.4*	*2.1*	*6.0*
	Total	*25*	*4.8 ± 2.3*	*1.4*	*79.3*
Tobongon	F	17	*7.8 ± 2.0*	*2.2*	*55.4*
	M	*5*	*4.0 ± 1.4*	*2.4*	*5.8*
	Total	*22*	*6.7 ± 2.0*	*3.8*	*55.4*
Total	*F*	*36*	*5.96 ± 1.97*	*1.40*	*79.27*
	M	*14*	*3.32 ± 2.41*	*0.51*	*6.00*
	Total	*50*	*5.06 ± 2.37*	*0.51*	*79.27*

According to the Kolmogorov-Smirnov test, the distribution of data of mercury hair from the Bolaang Mongondow area was not normal; instead, it had a log normal distribution. The geometrical mean is more suitable for log normal distribution data. Mean and Range of mercury concentration of each subgroups are presented in Table 1. The number of subjects with high mercury levels over 10 μg/g were 4 (18.8%), 2 (8%), and 0 (0%) in Tobongon, Tanoyan and the control group (Kotamobagu), respectively.

The mean hair mercury level of Bolaang Mongondow inhabitants is 5.06 (2.37) lies just above minimum level for danger according to HBM. Significant difference in the average mercury hair of inhabitants of ASGM area (Tobongon and Tanoyan) compared to Kotamobagu city (considered as control group). It seems the mercury contaminations in Bolaang Mongondow are more localized in small area of ASGM. There is no significant difference between average mercury level of Tobongon and Tanoyan (see Figure 3).

Figure 3. Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, Tobongon and Kotambagu.



The means of all subgroups are allready above HBM I and HBM II, except for Kotamobagu city inhabitants the mean is a bit above HBM I.

It is important to see the correlation between mercury concentration in scalp hairs of donors with their ages.

Figure 4. Mercury concentration in the scalp hair of gold miners, inhabitants living in ASGM area and outside were plotted agains ages.

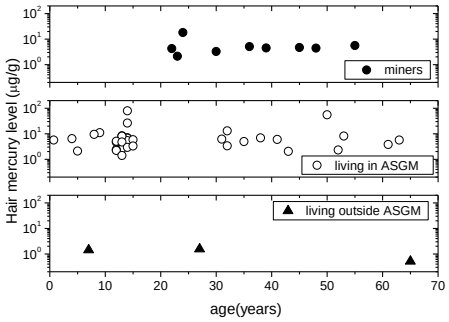


Table 2. *Correlation coefficient and Significancy for groups of donors of mercury concentration in Bolaang Mongondow.*

	Coeff.	**Sig.**
miners	0.43333	0.24395
Living in ASGM	0.05467	0.74443
Outside ASGM	-0.5	0.6667

From Table 2 we conclude that there is no significant correlation between hair mercury concentration and ages for all groups.

The Development of Minimata disease simptoms is seen when total mercury levels in hair reasched 50µg/g [17]. There are two cases of higher mercury in each ASGM site and both were females; 13 years old student from Tanoyan and 50 years old miners from Tobongon. Neurological examination has been performed on limited number of people in Tanoyan and Tobongon. The examination is aimed to observe twelve symptomps related to neurological disturbances associated with mercury posioning. The symptons are : (1) Signs of bluish discoloration of gums; (2) Rigidity and ataxia (walking or standing), (3) Alternating moivements or dysdiadochokinesia, (4) Irregular eye movements or nystagmnus, (5) Field of vision, (6) Knee jerk reflex, (7) Biceps reflex, (8) Babinski reflex, (9) Labial reflex, (10) Salivation and dysarthia, (11) Sensory examination and (12) Tremor.

Figure 5. Percentage of positive symptoms were observed among ASGM miners and inhabitants of Tanoyan and Tobongon.

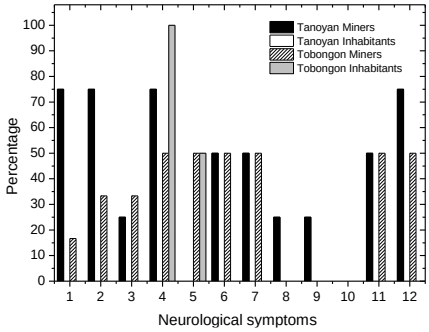


Figure 5 show that Tanoyan miners have four dominant symptoms compared to Tobongon miners who have no dominant symptoms among 12. Symptom #4 (nystagmus) is dominantly observed among Tanoyan miners and Tobongon inhabitants.

4. Conclusions

The means of hair mercury concentrations of inhabitants and gold miners of Tanoyan and Tabongon ASGM are higher than alert level of HBM II. While mean of hair mercury of inhabitants of Kotamobagu is about alert level only. It is imply that living outside ASGM area is better to reduce contamination from mercury. There was no significant correlation between ages of people and their hair mercury concentration. Females from ASGM area were found have excess mercury concentration more than 50 ppm.

Acknowledgements (Optional)

The authors wish to thank the government of Bolaang Mongondow regency, Indonesia for allowing us to do research and its support with sampling. One author (YIA) wishes to thank the Japanese Government for providing a Monbusho Scholarship for graduate studies in Ehime University.

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Review

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Reviewer's feedbacks for your manuscript to Mrs. Yayu Indriati Arifin

TREPSEA Conference <trepsea2018@gmail.com> 11 Juni 2019 09.26

Kepada: Yayu Arifin <yayu_arifin@ung.ac.id>, 竹原 麻里 <mtakehara@chikyu.ac.jp>

Dear Mrs. Yayu Indriati Arifin and co-authors

Thank you very much indeed for your reply including revised manuscript.
Hence, we will send again to the reviewers to check whether this revised manuscript follows and fulfills their comments and suggestions.

We will reply you after getting reviewers' feedback.

thanks and best regards

TREPSEA Committee

Mercury exposure from small scale gold mining activities and neurological symptoms on inhabitants and miners: a case study in Bolaang Mongondow, North Sulawesi Province, Indonesia

Yayu Indriati Arifin[1], Masayuki Sakakibara[2], Koichiro Sera[3], Fenty Usman Puluhulawa[4] , and Fitryane Lihawa[5].

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Keywords: mercury; ASGM; Bolaang Mongondow; pollution

1. Introduction

Gold mining activities in Bolaang Mongondow region is regionally known. The historical record showed that there was activities during Dutch colonial era [1]. From 1996 to 2004, Newmont Minahasa Raya (NMR) operated in Bakan of Bolaang Mongondow and produced about 8 kg of Gold per year [2]. Gold mineralization in Bakan is estimated has 10.32 tons of gold [3].

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According to the Kolmogorov-Smirnov test, the distribution of data of mercury hair from the Bolaang Mongondow area was not normal; instead, it had a log normal distribution. The geometrical mean is more suitable for log normal distribution data. Mean and Range of mercury concentration of each subgroup are presented in Table 1. The number of subjects with high mercury levels over 10 μg/g were 4 (18.8%), 2 (8%), and 0 (0%) in Tobongon, Tanoyan and the control group (Kotamobagu), respectively.

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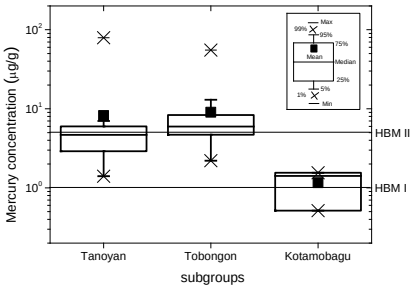

The means of all subgroups are already above HBM I and HBM II, except for Kotamobagu city inhabitants the mean is a bit above HBM I.

Figure 4. Mercury concentration in the scalp hair of gold miners, inhabitants living in ASGM area and outside were plotted against ages.

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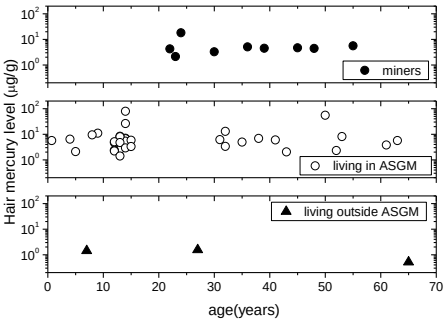

Table 2. *Correlation coefficient and Significancy for groups of donors of mercury concentration in Bolaang Mongondow.*

Subgroup (number)	**Coefficient**	**Significancy**
Miners (9)	0.43333	0.24395
Living in ASGM (38)	0.05467	0.74443
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From Table 2 we conclude that there is no significant correlation between hair mercury concentration and ages for all groups.

The Development of Minimata disease symptoms is seen when total mercury levels in hair reached 50μg/g [17]. There are two cases of higher mercury in each ASGM site and both were females; 13 years old student from Tanoyan and 50 years old miners from Tobongon. Neurological examination has been performed on limited number of people in Tanoyan and Tobongon. The examination is aimed to observe twelve symptomps related to neurological disturbances associated with mercury posioning. The symptons are : (1) Signs of bluish discoloration of gums; (2) Rigidity and ataxia (walking or standing), (3) Alternating movements or dysdiadochokinesia, (4) Irregular eye movements or nystagmnus, (5) Field of vision, (6) Knee jerk reflex, (7) Biceps reflex, (8) Babinski reflex, (9) Labial reflex, (10) Salivation and dysarthia, (11) Sensory examination and (12) Tremor.

Figure 5. Percentage of positive symptoms were observed among ASGM miners and inhabitants of Tanoyan and Tobongon.

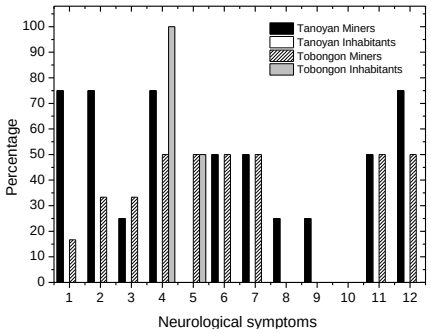

Figure 5 show that Tanoyan miners have four dominant symptoms compared to Tobongon miners who have no dominant symptoms among 12. Symptom #4 (nystagmus) is dominantly observed among Tanoyan miners and Tobongon inhabitants.

4. Conclusions

The means of hair mercury concentrations of inhabitants and gold miners of Tanoyan and Tabongon ASGM are higher than alert level of HBM II. While mean of hair mercury of inhabitants of Kotamobagu is about alert level only. It is implied that living outside ASGM area is better to reduce contamination from mercury. There was no significant correlation between ages of people and their hair mercury concentration. Females from ASGM area were found have excess mercury concentration more than 50 ppm.

Acknowledgements (Optional)

The authors wish to thank the government of Bolaang Mongondow regency, Indonesia for allowing us to do research and its support with sampling. One author (YIA) wishes to thank the Japanese Government for providing a Monbusho Scholarship for graduate studies in Ehime University.

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Mercury exposure from small scale gold mining activities and neurological symptoms on inhabitants and miners: a case study in Bolaang Mongondow, North Sulawesi Province, Indonesia

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***Abstract**: Mercury level in scalp hair of inhabitants and gold miners' livings at two artisanal and small-scale gold mining (ASGM) sites in Bolaang Mongondow regency of North Sulawesi Province was studied. Totally 50 scalp hairs were collected from Tanoyan, Tobongon and Kotamobagu city, and kept for further analysis. The mercury hair contents were determined using Particle Induced X-ray Emission (PIXE) at Nishina memorial research facility of Iwate Medical University of Japan. Mean levels of mercury in scalp hairs of inhabitants and ASGM workers were around 5 ppm. The highest mercury levels were found at females' miners in Tobongon and female teenagers in Tanoyan. Neurological assessment was conducted on several inhabitants and gold miners. 12 symptoms ((1) Signs of bluish discoloration of gums; (2) Rigidity and ataxia (walking or standing), (3) Alternating movements or dysdiadochokinesia, (4) Irregular eye movements or nystagmnus, (5) Field of vision, (6) Knee jerk reflex, (7) Biceps reflex, (8) Babinski reflex, (9) Labial reflex, (10) Salivation and dysarthia, (11) Sensory examination and (12) Tremor.) were used to describe the neurological disorder which may related to mercury expousure. It was found that nine neurological symptoms were dominantly observed among miners than inhabitants and three sypmtoms (8, 9 and 10) were less frequently observed.*

Keywords: *mercury; ASGM; Bolaang Mongondow; pollution.*

1. Introduction

Gold mining activities in Bolaang Mongondow region is regionally known. The historical record showed that there was activities during Dutch colonial era [1]. From 1996 to 2004, Newmont Minahasa Raya (NMR) operated in Bakan of Bolaang Mongondow and produced about 8 kg of Gold per year [2]. Gold mineralization in Bakan is estimated has 10.32 tons of gold [3].

Artisanal and Small-scale Gold mining activities are also found along activities of Gold mining companies, and it is regionally known, accepted even though there is no legal standing on the activities yet. There are several locations of ASGM in Bolaang Mongondow namely: Bakan, Modayag, Tanoyan and Tabongan. Local and national publications on the environmental, law issues are available [4]–[10]. Unfortunately, there is no comprehensive international report on subject yet. This study is aimed to provide the comprehensive analysis (ASGM activities, mercury pollution, health assessment and law) on the subject.

Such report is needed as baseline information on the mercury pollution from ASGM activities and its impact to inhabitant for specific region of Boolaang Mongondow. The published scientific information will help further related research activities in the region.

2. Method

Bolaang Mongondow is a region comprises vast area bordering Sulawesi Utara Province and Gorontalo Province. It was formerly known as Bolaang Mongondow Regency, now it is divided into several regencies (Bolaang Mongondow, Bolaang Mongondow Utara, Bolaang Mongondow Selatan, Bolaang Mongondow Timur and Kotamobagu city). Kotamobagu valley is located at higher elevation (about 180 to 130 m above sea level), is surrounded by mountains. Ambang mountain is a Nature reserve is just about one hour by car from the city [11]. It is a complex of volcanoes at western part of northern arm of Sulawesi [12].

2.1. Bolaang Mongondow–Tanoyan

Tanoyan ASGM is located in Bolaang Mongondow Timur regency and about 21 km from Kotamobagu city and can be reached in 35 minutes by car. The ASGM miner's camps are distributed along the Tanoyan river bank. The river is may contaminated by mercury from ASGM activities through direct way.

Figure 1. *The Tanoyan ASGM site showing* ***Figure 2***. *The Cyanidation plant in Tobongon, workshop of trommol in back site and bags of three cylinders left and four cylinders right and leftover of sediment waste in the foreground. pond of mining waste is behind.*

2.2. Bolaang Mongondow–Tobongon

Tobongon ASGM site is located Bolaang Mongondow Timur regency; it is about 13 km from the Kotamobagu city and can be reached in 22 minutes by car. The Tobongon mining area comprises about 4 km^2. The ore excavation sites are about 2 km along river bank and lies in the Tobongon river banks, which is very steep. Group of miners (5 persons) are working in each camp which are very close to each other (ten meters) along the very narrow river, which strong streams. They were using the only one ore processing site, just 50 meters from the river bank to the north. It is surrounded by houses, kiosks, and a mosque. There are ponds close to the mosque; the ponds were made using tailing bags. Fish cultivated in the ponds is being consumed by local populations.

Cyanidation plant is found at The Tobongon ASGM site. It consists of seven cylinders of about 3 meters in diameter and 7 meters high. The cynadiation plant receives tailing from Tobongon ASGM and outside.

We visited the ASGM locations during February 2015, where we conducted the following research activities:

- *Interview with head of villages, head/representative of ASGM locations, several gold miners and inhabitants.*
- *Taking scalp hairs of totally 50 gold miners and inhabitants.*
- *Taking the sediment samples from mining waste and nearby rivers.*

The procedure of interview, scalp hair collection and sediment sample collection are explained in detail [2]. The scalp hair samples were brought to Ehime University for preparation and later sent to Iwate Medical University for analysis using PIXE. The facility has been used for to identify the heavy metals in various samples, including human scalp hair [13]. The accuracy and precision of PIXE analysis on mercury concentration in the scalp hair has been discussed elsewhere [14], [15].

3. Result and Discussion

The distributions and range of mercury levels in 50 hair samples collected from the three sub districts are summarized in Table 1. The hair mercury concentrations of all participants are more than 1 μg/g, which indicates the toxicity level is already in alert level according to HBM [16].

Table 1. *Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, Tobongon and Kotambagu.*

Residence	Sex	N	Hair Mercury Content (μg/g)			
			Mean ± SD	Min	Max	
Kotamobagu	*F*	*1*	1.6 ± 1.8	1.6	1.6	
	M	2	0.97 ± 0.60	0.50	1.4	
	Total	3	1.2± 0.6	0.50	1.6	
Tanoyan	*F*	*18*	5.0 ± 2.6	1.4	79.3	
	M	7	4.3 ± 1.4	2.1	6.0	
	Total	25	4.8 ± 2.3	1.4	79.3	
Tobongon	*F*	*17*	7.8 ± 2.0	2.2	55.4	
	M	5	4.0 ± 1.4	2.4	5.8	
	Total	22	6.7 ± 2.0	3.8	55.4	
Total	*F*	*36*	*5.96 ± 1.97*	*1.40*		
79.27	*M*	*14*	*3.32 ± 2.41*	*0.51*		
6.00						
	Total	*50*	*5.06 ± 2.37*	*0.51*	*79.27*	

According to the Kolmogorov-Smirnov test, the distribution of data of mercury hair from the Bolaang Mongondow area was not normal; instead, it had a log normal distribution. The geometrical mean is more suitable for log normal

distribution data. Mean and Range of mercury concentration of each subgroup are presented in Table 1. The number of subjects with high mercury levels over 10 µg/g were 4 (18.8%), 2 (8%), and 0 (0%) in Tobongon, Tanoyan and the control group (Kotamobagu), respectively.

The mean hair mercury level of Bolaang Mongondow inhabitants is 5.06 (2.37) lies just above minimum level for danger according to HBM. Significant differences in the average mercury hair of inhabitants of ASGM area (Tobongon and Tanoyan) compared to Kotamobagu city (considered as control group). It seems the mercury contaminations in Bolaang Mongondow are more localized in small area of ASGM. There is no significant difference between average mercury level of Tobongon and Tanoyan (see Figure 3).

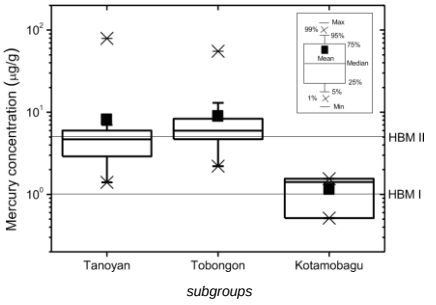

Figure 3. *Mercury concentration in the scalp hair hair of inhabitants and gold miners of Tanoyan, of gold miners, inhabitants living in ASGM area Tobongon and Kotamobagu. and outside were plotted against ages.*

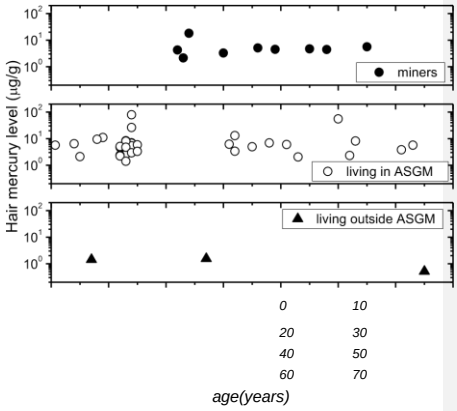

Figure 4. *Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, of gold miners, inhabitants living in ASGM area Tobongon and Kotamobagu. and outside were plotted against ages.*

The means of all subgroups are already above HBM I and HBM II, except for Kotamobagu city inhabitants the mean is a bit above HBM I.

Table 2. *Correlation coefficient and Significancy for groups of donors of mercury concentration in Bolaang Mongondow.*

Subgroup (number)	Coefficient	Significancy
Miners (9)	0.43333	0.24395

Living in ASGM (38)	0.05467	0.74443
Outside ASGM (3)	-0.5	0.6667

From Table 2 we conclude that there is no significant correlation between hair mercury concentration and ages for all groups.

The Development of Minimata disease symptoms is seen when total mercury levels in hair reached 50μg/g [17]. There are two cases of higher mercury in each ASGM site and both were females; 13 years old student from Tanoyan and 50 years old miners from Tobongon. Neurological examination has been performed on limited number of people in Tanoyan and Tobongon. The examination is aimed to observe twelve symptomps related to neurological disturbances associated with mercury posioning. The symptons are: (1) Signs of bluish discoloration of gums; (2) Rigidity and ataxia (walking or standing), (3) Alternating movements or dysdiadochokinesia, (4) Irregular eye movements or nystagmnus, (5) Field of vision, (6) Knee jerk reflex, (7) Biceps reflex, (8) Babinski reflex, (9) Labial reflex, (10) Salivation and dysarthia, (11) Sensory examination and (12) Tremor.

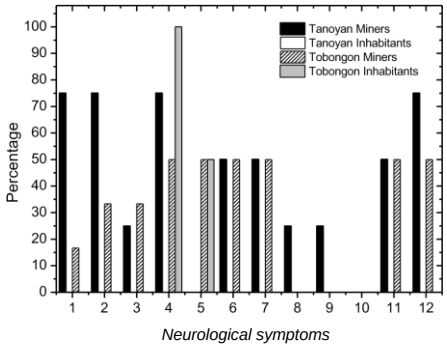

Figure 5. *Percentage of positive symptoms were observed among ASGM miners and inhabitants of Tanoyan and Tobongon.*

Figure 5 show that Tanoyan miners have four dominant symptoms compared to Tobongon miners who have no dominant symptoms among 12. Symptom #4 (nystagmus) is dominantly observed among Tanoyan miners and Tobongon inhabitants.

4. Conclusions

The means of hair mercury concentrations of inhabitants and gold miners of Tanoyan and Tabongon ASGM are higher than alert level of HBM II. While mean of hair mercury of inhabitants of Kotamobagu is about alert level only. It is implied that living outside ASGM area is better to reduce contamination from mercury. There was no significant correlation between ages of people and their hair mercury concentration. Females from ASGM area were found have excess mercury concentration more than 50 ppm.

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Publication status of your TREPSEA 2018 manuscript and information of TREPSEA 2021

TREPSEA Conference <trepsea2018@gmail.com> 4 Desember2020 12.49
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Gorontalo State University, Indonesia

First of all, we would like to inform the publication status of your manuscript which was submitted at TREPSEA 2018 International Conference.

We had published your manuscript entitled ***"Mercury exposure from small scale gold mining activities and neurological symptoms on inhabitants and miners: a case study in Bolaang Mongondow, North Sulawesi Province, Indonesia"*** *at the IOP Conference Series: Earth and Environmental Science.*

Please visit https://iopscience.iop.org/article/10.1088/1755-1315/589/1/012013
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Mercury exposure from small scale gold mining activities and neurological symptoms on inhabitants and miners: a case study in Bolaang Mongondow, North Sulawesi Province, Indonesia

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Keywords: *mercury; ASGM; Bolaang Mongondow; pollution.*

1. Introduction

Gold mining activities in Bolaang Mongondow region is regionally known. The historical record showed that there was activities during Dutch colonial era [1]. From 1996 to 2004, Newmont Minahasa Raya (NMR) operated in Bakan of Bolaang Mongondow and produced about 8 kg of Gold per year [2]. Gold mineralization in Bakan is estimated has 10.32 tons of gold [3].

Artisanal and Small-scale Gold mining activities are also found along activities of Gold mining companies, and it is regionally known, accepted even though there is no legal standing on the activities yet. There are several locations of ASGM in Bolaang Mongondow namely: Bakan, Modayag, Tanoyan and Tabongan. Local and national publications on the environmental, law issues are available [4]–[10]. Unfortunately, there is no comprehensive international report on subject yet. This study is aimed to provide the comprehensive analysis (ASGM activities, mercury pollution, health assessment and law) on the subject.

Such report is needed as baseline information on the mercury pollution from ASGM activities and its impact to inhabitant for specific region of Boolaang Mongondow. The published scientific information will help further related research activities in the region.

2. Method

Bolaang Mongondow is a region comprises vast area bordering Sulawesi Utara Province and Gorontalo Province. It was formerly known as Bolaang Mongondow Regency, now it is divided into several regencies (Bolaang Mongondow, Bolaang Mongondow Utara, Bolaang Mongondow Selatan, Bolaang Mongondow Timur and Kotamobagu city). Kotamobagu valley is located at higher elevation (about 180 to 130 m above sea level), is surrounded by mountains. Ambang mountain is a Nature reserve is just about one hour by car from the city [11]. It is a complex of volcanoes at western part of northern arm of Sulawesi [12].

2.1. Bolaang Mongondow–Tanoyan

Tanoyan ASGM is located in Bolaang Mongondow Timur regency and about 21 km from Kotamobagu city and can be reached in 35 minutes by car. The ASGM miner's camps are distributed along the Tanoyan river bank. The river is may contaminated by mercury from ASGM activities through direct way.

Figure 1. *The Tanoyan ASGM site showing* ***Figure 2***. *The Cyanidation plant in Tobongon, workshop of trommol in back site and bags of three cylinders left and four cylinders right and leftover of sediment waste in the foreground. pond of mining waste is behind.*

2.2. Bolaang Mongondow–Tobongon

Tobongon ASGM site is located Bolaang Mongondow Timur regency; it is about 13 km from the Kotamobagu city and can be reached in 22 minutes by car. The Tobongon mining area comprises about 4 km^2. The ore excavation sites are about 2 km along river bank and lies in the Tobongon river banks, which is very steep. Group of miners (5 persons) are working in each camp which are very close to each other (ten meters) along the very narrow river, which strong streams. They were using the only one ore processing site, just 50 meters from the river bank to the north. It is surrounded by houses, kiosks, and a mosque. There are ponds close to the mosque; the ponds were made using tailing bags. Fish cultivated in the ponds is being consumed by local populations.

Cyanidation plant is found at The Tobongon ASGM site. It consists of seven cylinders of about 3 meters in diameter and 7 meters high. The cynadiation plant receives tailing from Tobongon ASGM and outside.

We visited the ASGM locations during February 2015, where we conducted the following research activities:

- *Interview with head of villages, head/representative of ASGM locations, several gold miners and inhabitants.*
- *Taking scalp hairs of totally 50 gold miners and inhabitants.*
- *Taking the sediment samples from mining waste and nearby rivers.*

The procedure of interview, scalp hair collection and sediment sample collection are explained in detail [2]. The scalp hair samples were brought to Ehime University for preparation and later sent to Iwate Medical University for analysis using PIXE. The facility has been used for to identify the heavy metals in various samples, including human scalp hair [13]. The accuracy and precision of PIXE analysis on mercury concentration in the scalp hair has been discussed elsewhere [14], [15].

3. Result and Discussion

The distributions and range of mercury levels in 50 hair samples collected from the three sub districts are summarized in Table 1. The hair mercury concentrations of all participants are more than 1 μg/g, which indicates the toxicity level is already in alert level according to HBM [16].

Table 1. *Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, Tobongon and Kotambagu.*

Residence	Sex	N	Hair Mercury Content (μg/g)			
			Mean ± SD	Min	Max	
Kotamobagu	*F*	*1*	1.6 ± 1.8	1.6	1.6	
	M	2	0.97 ± 0.60	0.50	1.4	
	Total	3	1.2± 0.6	0.50	1.6	
Tanoyan	*F*	*18*	5.0 ± 2.6	1.4	79.3	
	M	7	4.3 ± 1.4	2.1	6.0	
	Total	25	4.8 ± 2.3	1.4	79.3	
Tobongon	*F*	*17*	7.8 ± 2.0	2.2	55.4	
	M	5	4.0 ± 1.4	2.4	5.8	
	Total	22	6.7 ± 2.0	3.8	55.4	
Total	*F*	*36*	*5.96 ± 1.97*	*1.40*		
79.27	*M*	*14*	*3.32 ± 2.41*	*0.51*		
6.00						
	Total	*50*	*5.06 ± 2.37*	*0.51*	*79.27*	

According to the Kolmogorov-Smirnov test, the distribution of data of mercury hair from the Bolaang Mongondow area was not normal; instead, it had a log normal distribution. The geometrical mean is more suitable for log normal

distribution data. Mean and Range of mercury concentration of each subgroup are presented in Table 1. The number of subjects with high mercury levels over 10 µg/g were 4 (18.8%), 2 (8%), and 0 (0%) in Tobongon, Tanoyan and the control group (Kotamobagu), respectively.

The mean hair mercury level of Bolaang Mongondow inhabitants is 5.06 (2.37) lies just above minimum level for danger according to HBM. Significant differences in the average mercury hair of inhabitants of ASGM area (Tobongon and Tanoyan) compared to Kotamobagu city (considered as control group). It seems the mercury contaminations in Bolaang Mongondow are more localized in small area of ASGM. There is no significant difference between average mercury level of Tobongon and Tanoyan (see Figure 3).

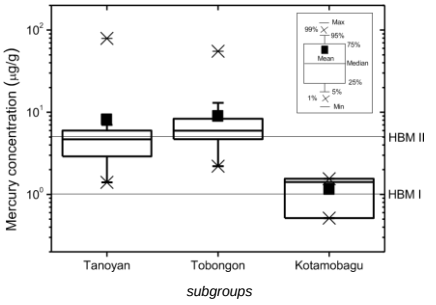

Figure 3. *Mercury concentration in the scalp hair hair of inhabitants and gold miners of Tanoyan, of gold miners, inhabitants living in ASGM area Tobongon and Kotamobagu. and outside were plotted against ages.*

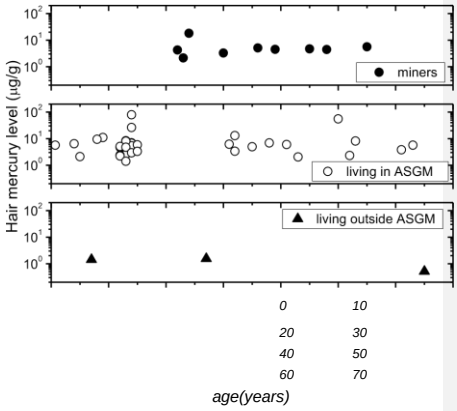

Figure 4. *Mercury concentration in the scalp hair of inhabitants and gold miners of Tanoyan, of gold miners, inhabitants living in ASGM area Tobongon and Kotamobagu. and outside were plotted against ages.*

The means of all subgroups are already above HBM I and HBM II, except for Kotamobagu city inhabitants the mean is a bit above HBM I.

Table 2. *Correlation coefficient and Significancy for groups of donors of mercury concentration in Bolaang Mongondow.*

Subgroup (number)	Coefficient	Significancy
Miners (9)	0.43333	0.24395

Living in ASGM (38)	0.05467	0.74443
Outside ASGM (3)	-0.5	0.6667

From Table 2 we conclude that there is no significant correlation between hair mercury concentration and ages for all groups.

The Development of Minimata disease symptoms is seen when total mercury levels in hair reached 50μg/g [17]. There are two cases of higher mercury in each ASGM site and both were females; 13 years old student from Tanoyan and 50 years old miners from Tobongon. Neurological examination has been performed on limited number of people in Tanoyan and Tobongon. The examination is aimed to observe twelve symptomps related to neurological disturbances associated with mercury posioning. The symptons are: (1) Signs of bluish discoloration of gums; (2) Rigidity and ataxia (walking or standing), (3) Alternating movements or dysdiadochokinesia, (4) Irregular eye movements or nystagmnus, (5) Field of vision, (6) Knee jerk reflex, (7) Biceps reflex, (8) Babinski reflex, (9) Labial reflex, (10) Salivation and dysarthia, (11) Sensory examination and (12) Tremor.

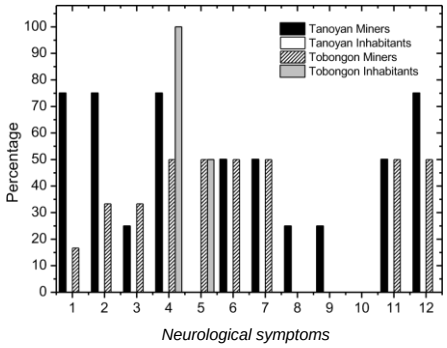

Figure 5. *Percentage of positive symptoms were observed among ASGM miners and inhabitants of Tanoyan and Tobongon.*

Figure 5 show that Tanoyan miners have four dominant symptoms compared to Tobongon miners who have no dominant symptoms among 12. Symptom #4 (nystagmus) is dominantly observed among Tanoyan miners and Tobongon inhabitants.

4. Conclusions

The means of hair mercury concentrations of inhabitants and gold miners of Tanoyan and Tabongon ASGM are higher than alert level of HBM II. While mean of hair mercury of inhabitants of Kotamobagu is about alert level only. It is implied that living outside ASGM area is better to reduce contamination from mercury. There was no significant correlation between ages of people and their hair mercury concentration. Females from ASGM area were found have excess mercury concentration more than 50 ppm.

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