ENVIRONMENTAL IMPACT OF ARTISANAL GOLD MINING AT CIKANGEAN RIVER IN MULYAJAYA VILLAGE, GARUT, WEST JAVA

Retno Damayanti and M. Lutfie
R&D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211
Ph. 022-6030483, Fax. 022-6003373
e-mail: retnod@tekmira.esdm.go.id; lutfi@tekmira.esdm.go.id

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ABSTRACT

The artisanal and small scale gold mining usually utilize mercury for its gold recovery. Mercury is used as the best alternative by many miners due to its effectiveness, simple and cheap process for gold recovery. The increasing mercury utilization motivates tekMIRA to prevent more pollution caused by uncontrolled or incorrect mercury utilization. For this purpose, the artisanal gold mining located in Mulyajaya Village, Garut was chosen for monitoring mining activities. Grab sampling method was used to evaluate environmental monitoring on terrestrial water and its sediment, soil and tailing surrounding the artisanal gold mining.

The monitoring results show that mercury was found in all waters and sediment surrounding the artisanal gold mine. The mercury concentration in river sediment was around 0.08 – 0.15 ppm and this was higher than its concentration in the river water (0.0002 ppm). The same concentration occurred at the upstream and downstream (0.0002 ppm). The mercury concentration in the sediment coming from sedimentation pond were 2.27 – 7.60 ppm. Eventhough the mercury was still in low concentration either in the water or in the sediment, a guidance should be delivered to the miners about the danger of mercury substances used in the mining activities.

Keywords: artisanal gold mining, mercury, environmental impact, monitoring

1. INTRODUCTION

Mercury has been used in the recovery of gold by artisanal and small scale gold mining activities since last century (Hunerlach et.al., 2000). Amalgamation process is mostly applied either for gold alluvial and gold primary deposits because this is quite effective, simple and cheap process. Due to its easy and simple process there is a significance increase using amalgamation process in the artisanal gold mining. And no control of the mercury emission toenvironment.

There are several form of mercury, including elemental mercury, ionic (or oxidized) mercury Hg(II), and an organic forms such as methylmercury. Methylmercury is the most readily incorporated into biological tissues and the most toxic to humans. The transformation from elemental mercury Hg(0) to methylmercury (CH_3Hg^+) is a complex biogeochemical process that requires at least two steps, i.e. the oxidation of Hg(0) to Hg(II) followed by transformation from Hg(II) to CH_3Hg^+. The second transformation step is referred to methylation (Hunerlach et.al., 2000).

The mercury methylation is controlled by sulfate-reducing bacteria and other microbes that tend to thrive in conditions of low dissolved oxygen, such as the sediment–water interface. Numerous environmental factors influence the rates of mercury methylation and the reverse reaction known as demethylation. These factors include temperature, dissolved organic carbon, salinity, acidity (pH), oxidation-reduction conditions, and the form and concentration of sulfur in water and sediments. The concentration of CH_3Hg^+ generally increases by a factor of ten or less with each step up the food chain, a process known as biomagnification. Biomagnification is the incremental increase in concentration of a contaminant at each level of a food chain (Anonymous, 1995).

Therefore, even though the concentrations of Hg(0), Hg(II), and CH_3Hg^+ in water may be very low and deemed safe for human consumption as drinking water, CH_3Hg^+ concentration levels in fish, especially predatory species such as bass and catfish, may reach levels that are considered potentially harmful to humans and fish-eating wildlife, such as bald eagles (Hunerlach et.al., 2000).

Like many environmental contaminants, mercury undergoes bioaccumulation. Bioaccumulation is the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them. The amount of mercury in their body accumulates over time. If for a period of time an organism does not ingest mercury, its body burden of mercury will decline. If, however, an organism continually ingests mercury, its body burden can reach toxic levels. The rate of increase or decline in the body is specific for each organism. For humans, about half of mercury can be eliminated in 70 days if no more mercury is ingested during that time (Anonymous, 1995).

This paper is based on research findings (environmental monitoring) in the artisanal gold mine site, Garut, West Java, located at Mulyajaya village (Figure 1). The mine prospects dominantly covered in Bunder Hill. Sampling location can be seen in Figure 2.

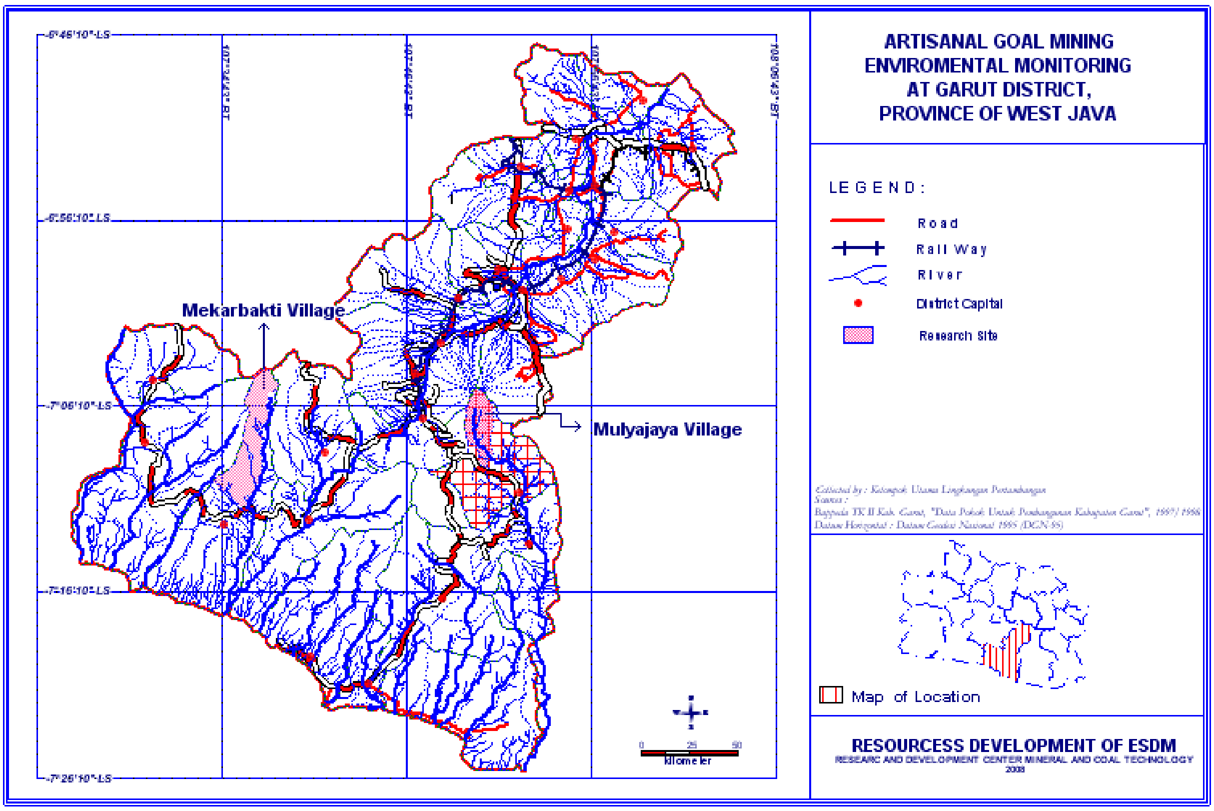

Figure 1. Location of artisanal gold mine in Garut District, West Java

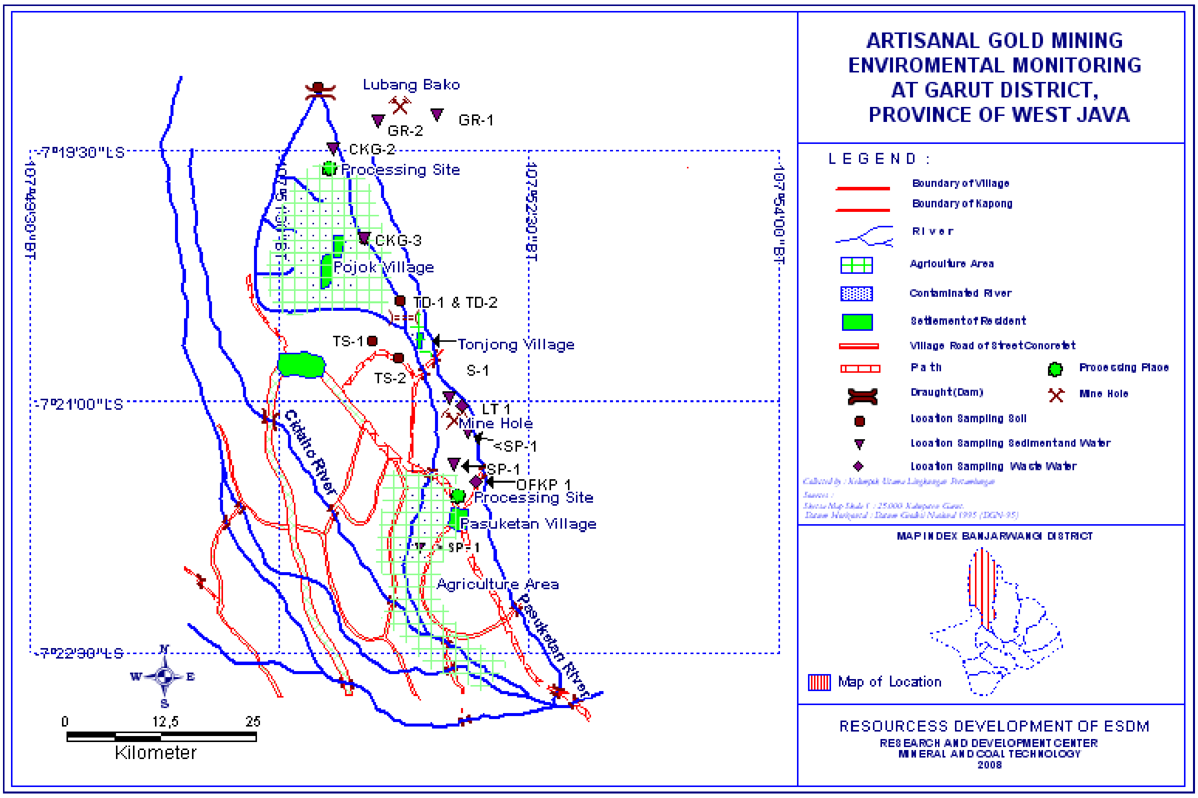

Figure 2. Sampling location for water, water and sediment at Mulyajaya Village

Artisanal mining is an important economic sector in many developing countries. However, limited resources and training, and the availability of cheap, but potentially hazardous methods of extraction and processing of minerals can cause significant threats to both miners and the local environment (Ogola, 2002).

The main objective of this research was to evaluate the environmental impact, the levels of Hg and some heavy metals such as Pb, Cu and Zn. then inform the local government about those information. In the future, the authorized institutions can educate local communities on safe and environmentally sound mining and mineral processing techniques. This can be achieved through organizing a good mining practice for miners.

2. MATERIALS AND RESEARCH METHODS

2.1. Materials

- solid waste samples in the form of amalgamation slurry were taken from settling pond.
- waste water samples were taken from overflow settling pond.
- water samples were collected from river and other waters before, after and at the processing unit that predited having an adverse impact to environment.
- Soil samples were taken from upstream area

2.2. Reagents and Equipment

Reagents and equipments used in this research including Nitric acid p.a., X-Ray Diffraction (XRD) Equipment, Atomic Absorption Spectrophotometry (AAS), Electrical Conductivity, Temperature and pH meter

2.3. Methods

This research evaluation was mostly based on the primary data which taken directly from the site. Some physical parameters for water and waste water analysis were measured on site such as pH, electric conductivity and temperature. Metals parameter in water was analyzed after preserved by nitric acid to the pH of 2.

Based on field survey, it was decided to do a grab sampling method that conducted at certain time and place. The samples expected to be capable showing the composition of the contaminant at this period of time.

Water collected from rivers around the artisanal mining and waste water was sampled from the outflow of settling pond. The sediment samples from the bottom of river were taken for checking the mercury availability in the pond sediment.

Rock sample was taken from mine hole and its composition was determined by XRD. The concentration of gold, silver and heavy metals which existed as impurities were determined by atomic absorption spectrophotometry (AAS).

The quality of water surrounding the artisanal gold mining can be assessed by comparing measured parameter on site using Regulation Standard for Water Class I in PP No. 82/2001 Dated on December 14th, 2001 and Waste Water Regulation Standard in the Ministry of Environmental Decree No. Kep-51/MenLH/10/1995.

Water and soil quality methods used in the monitoring were varied greatly depending on the measured parameters as can be seen in Table 1.

3. RESULTS AND DISCUSSION

The XRD analysis shows that the rocks were composed of quartz (SiO_2), illite ($KAl_2Si_3AlO_{10}(OH)_2$) and hematite (a-Fe_2O_3). This composistion is suitable with secondary data of Bunder Hill geological map that was mostly consisted of hematite mineral. Pyrite was not found in this surrounding area, so a preliminary study for acid drainage formation could be ignored for Aju Mine Hole but other mine holes must be checked to prevent acid drainage formation. This is not so easy because only few artisanal miners who wants to make cooperation.

Fire assay and chemical analysis of Aju Mine Hole show the concentration of Au and Ag were 2.27 g/ton and 24.49 g/ton respectively. Concentration of other metals were 3.13 % of iron (Fe), 0.15 % of manganese (Mn), 40 ppm of lead (Pb), 60 ppm of copper (Cu), and 40 ppm of zinc (Zn). Cadmium (Cd) and chrom (Cr) were undetected in the rocks samples.

The result of metals analysis of soil is shown in Table 2. Soils located near dam area and before irrigation channel were sampled with assumption that those areas were not contaminated by artisanal mining activities. The soil of rice field after irrigation channel was sampled to get information about soil conditon after gold processing.

Table 1. Analysis methods for water quality

Parameter	Analysis Methods	Principle
Physics		
Temperature	Termometer	Measurement is based on mercury expansion
Electical conductivity	Conductivity meter	Measuring electricity using an electrode
Parameter	Analysis Methods	Principle
Chemistry		
Total Dissolved Solids	Gravimetry	Determining sample weight after vapourizing at the temperature of 105 ºC
Total Suspended Solids	Gravimetry	Suspended solid containing filter produced from filtering process was dried at 105 ºC then weighed.
pH	pH-meter	Measurement based on potential difference between electrodes used in the equipmet.
Heavy metals	Spectrophotometry	Liquid sample was aspirated in the flame then atomized.

Table 2. Metals analysis of soil samples from Dam Location and Aju gold processing unit

Parameter	Units	Canadian **Guidelines (*) in ppm**	Sample Code			
			TD-1	TD-2	TS-1	TS-2
Fe	%	-	0.248	0.247	0.306	0.232
Mn	%	-	0.014	0.015	0.007	0.003
Pb	ppm	375	130	90	120	130
Cu	ppm	150	60	50	80	60
Zn	ppm	600	140	120	130	130
Hg	ppm	0.8	0.136	0.205	0.151	0.234

Note:
TD-1 : Soil sample located near dam area on the depth of 0 – 50 cm
TD-2 : Soil sample located near dam area on the depth of 50 – 100 cm
TS-1 : Rice field soil after irrigation channel
TS-2 : Rice field soil before irrigation channel
(*) : Canadian Guidelines for the Agricultural Land

Indonesia has no guidelines for soils especially for heavy metals concentration. Therefore a comparison for this heavy metals research must follow other guidelines, in this case using The Canadian guidelines for soils (Table 2).

Metals concentrations at dam area and processing unit were varied, the important indication was the ability of mercury in those soil samples. Mercury concentration at the control site varied in the range of 0.136 – 0.205 ppm. Rice field soil also indicated high concentration level of about 0.151 – 0.234 ppm. It means that the control areas that were predicted free from heavy metals contamination, had been influenced by artisanal mining activities. Due to this fact, more stringent control must be applied to artisanal miner to prevent adverse impact to human and the environment.

The waste water were taken from 2 location (Aju mine hole and settling pond 1). Visually, the waste water condition was very different with surface water. The physical and chemical condition of waste water can be seen in Table 3. The pH did not differ significantly compared to other surface waters. However, the suspended solid and also its heavy metals concentration in the waste water were found 3 – 4 times higher than surrounding waters. In the outflow of settling pond 1, cadmium and chrom were not detected.

Mercury concentration found in mine hole water sample was twice higher than its concentration in other water samples. This is caused by the miners activity of testing the gold availability. Mercury concentration coming from the settling pond outflow sample was similiar with its concentration in the most surface water samples (0.0002 ppm).

Other water monitoring were conducted at the surrounding artisanal mining. There were 9 (nine) locations of sampled surface water:
- Upper part of Cikangean river
- Cikangean river at the location of bullion processing
- Cikangean river after processing area
- Geurewek area before Bako mine hole
- Geurewek area after Bako mine hole
- Water spring before Aju mine hole
- Irrigation channel before Aju mine hole
- Irrigation channel near by Aju mine hole
- Irrigation channel after Aju mine hole

Visually, water conditions at nine sampling points were clear which are supported by low suspended solid concentration in the upper and down stream location. High suspended solid concentration of 10 mg/l found at the junction of Cikangean river and waters from Geureuwek area. This might be caused by turbulence in this area.

Water samples analysis data can be seen on Table 4. Generally, river waters were slightly acidic to neutral condition. The water pH were in the range of 5 - 6. High concentration of iron (Fe) and manganese (Mn) were found in the waters due to the main mineral composition was hematite. Other metals such copper (Cu), cadmium (Cd), lead (Pb), zinc (Zn)and chrom (Cr) were detected in low concentration.

Table 3. Metals analysis of waste water sample from the artisanal gold mining

Parameter	Unit	Sample Code		Environmental Ministry Decree No.	
		LT-1	OFKP-1	202/2004	51/1995
pH		6	5	9-Jun	9-Jun
DHL	mhos	90	55		
T	°C	22	24		
Suspended Solid		47	19	200	200
Dissolved Solid	mg/l	292	333		200
Fe	mg/l	2.67	1.51		5
Mn	mg/l	0.1	0.4		2
Cu	mg/l	tt	tt	2	2
Pb	mg/l	0.04	0.05	1	0.1
Zn	mg/l	0.03	0.01	5	5
Cd	mg/l	<0.01	tt	0.1	
Cr	mg/l	0.04	tt	1	0.54
Hg	mg/l	0.0004	0.0002	0.05	

Note:
LT-1 : Waste water from Aju mine hole
OFKP : Overflow from settling pond 1

Table 4. Metals analysis in water samples from location surrounding the artisanal gold mining

Parameter	Unit	Samples Code									BMA
		CKG-1	CKG-2	CKG-3	GR-1	GR-2	<SP-1	SP-1	>SP-1	S-1	**Class. I**
pH		5	6-May	6	6-May	5	6-May	5	6	6	9-Jun
DHL	μmhos	100	95	23.5	110	120	100	65	100	130	
T	°C	19	20	95	19	19	21.5	21.5	22	20	
Suspended Solid		3	10	5	42	11	31	35	54	99	50
Dissolved Solid	mg/l	303	496	207	147	109	223	129	185	187	1000
Fe	mg/l	0.23	0.27	0.68	1.15	0.17	1.74	2.55	1.59	2.73	0.3
Mn	mg/l	0.03	0.03	0.07	0.15	0.03	0.1	0.32	0.11	0.18	0.1
Cu	mg/l	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02
Pb	mg/l	0.03	<0.01	0.01	0.03	nd	0.06	nd	0.01	nd	0.03
Zn	mg/l	<0.01	<0.01	0.01	0.03	0.02	0.03	0.05	0.02	0.03	0.05
Cd	mg/l	nd	nd	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Cr	mg/l	nd	nd	nd	0.02	0.03	nd	0.01	0.03	0.03	0.05
Hg	mg/l	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.001

Keterangan:
nd : not detected
CKG-1 : Upper stream of Cikangean River
CKG-2 : Cikangean River at gelundung site
CKG-3 : Cikangean River after processing unit
GR-1 : Geureuwek before Bako mine hole
S-1 : Spring water before Aju mine hole
<SP-1 : Irrigation channel before processing unit
SP-1 : Irrigation channel at processing unit
>SP-1 : Irrigation channel after processing unit
GR-2 : Geureuwek after Bako mine hole
BMA : Regulation Standard for Water Class I in Government Regulation No. 82/2001 Dated on December 14th, 2001

(Zn) and mercury (Hg) were detected in the range concentration of 0.01 – 0.06 ppm for Pb, 0.01 – 0.05 ppm for Zn and 0.0002 ppm for Hg. Mercury was also detected at the upper stream (CKG-1 and GR-1) and spring water (S-1). This was caused by miners activities during checking gold availability using mercury.

Sediment samples (eleven sampling locations) were collected from spring water (S-1), Cikangean river(CKG-1, CKG-2, CKG-3), Gereweuk waters (GR-1, GR-2), irrigation channels (<SP-1, SP-1, >SP-1) and settling pond (KP-1 dan KP-2) near Aju processing unit.

Table 5 and 6 show metal concentration in sediment samples. The concentration of metals such as Fe, Mn, Cu, Pb, Zn, Cd and Hg were higher than those of water samples because these high molecular weights made them settle at the bottom of the water.

The mercury concentration detected at the bottom of river (sediment) was 400 – 750 times more higher compared to the concentration in river water samples. Its concentration in the irrigation channel was about 300 - 400 times higher than in the river water samples. At the settling pond area, the mercury concentration was about 2.27 – 7.60 ppm.

Table 5. Sediment analysis from the bottom of the river around artisanal gold mining

Parameter	Unit	Sample Code						Average Metal Concentration
		CKG-1	CKG-2	CKG-3	GR-1	GR-2	S-1	
Fe	%	6.71	6.13	6.90	9.20	8.89	8.16	
Mn	%	0.066	0.073	0.097	0.128	0.103	0.131	
Cu	ppm	50	50	60	70	70	40	45
Pb	ppm	nd	850	nd	108	430	370	20
Zn	ppm	590	750	1280	1840	1550	950	95
Cd	ppm	20	60	60	30	30	50	0.3
Hg	ppm	0.09	0.14	0.15	0.12	0.08	0.07	0.4

Note:
CKG-1 : Sediment from upstream of Cikangean river
CKG-2 : Sediment from Cikangean river near bullion gold processing
CKG-3 : Sediment from Cikangean after processing unt
GR-1 : Sediment at Geureuwek before Bako mine hole
GR-2 : Sediment Geureuwek after Bako mine hole
S-1 : Spring water before Aju mine hole
nd : not detected
Estimated average metals concentration in surface water sediment by Turekian and Wedepohl (Dojlido and Best, 1993)

Table 6. Sediment analysis at gold processing area and settling pond

Parameter	Unit	Sample Code					USEPA PEC
		<SP-1	SP-1	>SP-1	KP-1	KP-2	
Fe	%	15.95	8.60	8.17	4.36	6.09	
Mn	%	0.227	0.222	0.091	0.099	0.903	
Cu	ppm	60	50	60	90	230	197
Pb	ppm	690	1170	nd	1900	11400	91.3
Zn	ppm	1900	1480	1380	2730	8610	315
Cd	ppm	10	30	nd	70	140	3.53
Hg	ppm	0.06	0.06	0.08	7.60	2.27	0.486

Note:
<SP-1 : Irrigation Channel Sediment before gold processing location
SP-1 : Irrigation Channel Sediment at gold processing location
>SP-1 : Irrigation Channel Sediment after gold processing location
KP-1 : Sediment at settling pond 1
KP-2 : Sediment at settling pond 2
nd : not detected
* : in %
USEPA PEC : United State Environmental Protection Agency Probable Effect Level

Environmental impact and health effect

Artisanal gold mines have not generally fulfilled regulation either in mining or in the processing. The most important aspect, the mine area is usually abandoned and there is no plan for assessing the environmental impacts. Moreover, the health effects caused by mercury inhalation and other metal intoxication coming from gold processing activities are also normally ignored.

The significant effects on miners and people living surrounding artisanal mining have not been known yet during the study. However, the possible adverse effect on health could be predicted based on several field data. Those data are important for the people who live there and the miners themselves.

Artisanal mining at Mulyajaya village was conducted using underground mine system. After extracting its gold, the mine holes were abandoned if the miners could not collect anything. These will disturb the protected forest area where most artisanal gold mines exist and finally it will cause erosion and flood.

Environmental pollution due to heavy metal contamination, such as mercury and lead, occurred nearly, shown by heavy metal concentration found in soils, sediments and even in the water samples.

In the process of burning bullion, most miners used conventional burning method in the rooms which are used for routine family activities. Testing of gold recovery sometimes use the dining equipment. The uncontrolled utilization of mercury can cause dangerous effects to the environment and human health. This study shows that soil from outside artisanal mining has been contaminated by mercury.

The risk of mercury pollution toward human health might come from:

- Consuming food contaminated by mercury.
- Incorrect handling of mercury for amalgamation
- Incorrect handling of mercury in tailing.
- Mercury vapour inhalation during roasting the gold bullions.
- Consuming unsafe water for daily activities.

Accumulation of mercury gradually will affect the surrounding environment and human health. Effect on human health will be seen after several years. Once it accumulate in human tissues it will stay permanently. Mercury contamination in human body normally is called as mercury intoxication.

On the monitoring activities, other heavy metals such as lead (Pb), zinc (Zn) and copper (Cu) were also found in soil and sediment samples. Their concentration in water samples were not so high. If the water at surrounding artisanal gold mine becomes acid, these heavy metals will be dissolved immediately. Like mercury, these metals will also impress the human central nervous system.

Due to heavy metals in water are influenced dominantly by pH condition, the acid mine drainage generation in surrounding artisanal gold mine must be monitored thouroughly to prevent the generated sulphuric acid that can dissolve those heavy metals bearing in gold ores.

4. CONCLUSION

– Mineral ores at Aju mine hole were composed by quarst (SiO_2), illite ($KAl_2Si_3AlO_{10}(OH)_2$) and hematite (a-Fe_2O_3) with Au and Ag concentrations of 2.27 g/ton and 24.49 g/ton respectively.

– Metals containing in the rock minerals were Fe (3.13 %), Mn (0.15 %), Pb (0.004 %), Cu (0.006 %), and Zn (0.004 %). Cadmium (Cd) and chromium (Cr) were not detected in the mineral samples.

– In this preliminary study, there was no pyritic minerals in the mine hole. However, acid drainage test must be checked at the mine hole because acidic pH water was found at surrounding mine areas.

– Mercury was found in water and sediment samples from the artisanal mining activities, but compare to its concentration in the sediment (0.08 – 0.15 ppm), the mercury concentration in water was quite low (0.0002 ppm). In the upstream location, the low concentration of mercury can be detected either in water (0.0002 ppm) or in the sediment (0.07 ppm).

– In the irrigation channel, mercury concentration in water was relatively low (0.0002 – 0.0003 ppm). In the sediment the concentraton was 0.06 – 0.08 ppm.

- Water in Aju mine hole had concentration of mercury about 0.0004 ppm and in run off from its sedimentation pond was about 0.0002 ppm.
- Mercury concentration in the sediment became higher at the sedimentation pond (2.27 – 7.60 ppm).

- Water in the survey area was slightly acid to neutral so it is suggested to control its condition because most miners used mercury for extracting gold while the rock material also contained heavy metals such as Pb, Cu and Zn. This is important to anticipate the natural leaching which might happen easily in acidic condition.

5. SUGGESTION

- Physical and chemical data collected during this preliminary survey was not enough to assess the detail condition in this mining area. Local government should have planned continually to monitore at the location of the artisanal gold mining especially that have tendency of having flood during certain time to

- Eventhough the mercury was still in low concentration either in the water or in the sediment, a guidance should be delivered to the miners about the danger of mercury substances used in the mining activities.

- The product from amalgamation process should be kept in the proper manner because of its mercury content.

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REFERENCES

Anonimous, 1995. Mercury Contamination in Aquatic Ecosystem, *USGS Fact Sheet 216-95,* p. 1 – 4.

Beak International Incorporated, 2002. *Literature Review of Environmental Toxicity of Mercury, Cadmium, Selenium and Antimony in Metal Mining Effluents*, Canada, p. 2.1 – 2.7.

Dojlido, J. and Best, G.A., 1993. *Chemistry of Water and Water Pollution*, 1st Ed., Ellis Howard Ltd., Great Britain, p. 17.

Hunerlach, M.P., J.J. Rytuba and C.N. 2000. *Alpers, Mercury Contamination from Hydraulic Placer-Gold Mining in the Dutch Flat Mining District*, California, p. 1 - 6.

Ogola, J.S., W.V. Mitullah and M.A. Omulo, 2002. Impact of Gold Mining on the Environment and Human Health: A Case Study in the Migori Gold Belt, Kenya, *Environmental Geochemistry and Health* 24: p. 141 – 158.