H-7 Interdisciplinary Study on Environmental Management, Planning and Risk Communication in Gold Rush Regions

(Abstract of the Final Report)

Contact person Satoshi Murao
Senior Research Scientist, Institute for Geo-Resources and Environment, National Institute of Advanced Industrial Science and Technology
Tsukuba Central No.7, Higashi 1-1-1, Tsukuba, 305-8567 Japan
TEL: +81-29-861-2402; FAX: +81-29-861-3717
E-mail: s.murao@aist.go.jp

Total Budget for FY2000-FY2002 78,218,000 Yen (**FY2002**; 25,740,000 Yen)

Key Words small-scale mining, mercury, gold, environment, risk perception, GIS

1. Introduction

Large number of people are often clandestinely exploiting mineral deposits with rudimentary tools in many emerging countries[1]. Such activity is called artisanal or small-scale mining, and "gold rush" when they recover gold. Those who engaged in artisanal/small-scale mining are called artisanal/small-scale miners. This type of mining has recently come to a social attention due to the large impact on the environment. Small-scale miners usually use mercury and cyanide to recover refractory gold. Careless handling or lack of knowledge about such chemical materials may cause adverse effects on people's health and the environment. Especially mercury contamination is of great concern. This study aimed at finding an interdisciplinary framework in order to address complex problems arising from small-scale mining of gold. The study was divided into four sub-themes to treat the issue from (1) basic research on geochemical behavior of mercury, (2) identification and mapping of potential gold zones, (3) estimation of mercury emission based on geological knowledge and (4) field investigation of mercury contamination and a trial of risk communication.

2. Research Objective

(1) Basic research on geochemical behavior of mercury

For the environmental management of mercury, we need to know its fate from the initial stage to later stages of the contamination. Thus this sub-theme intended to clarify the fate of mercury in time around a gold mining site in the Philippines.

In contaminated sites, water is a major transporting medium of contaminants and we aimed at the development of an easy system to analyze contaminated water samples of limited volume. We planned to improve the non-vacuum PIXE at Hiroshima University and to optimize the analytical conditions.

(2) Identification and mapping of potential gold zones

For the environmental planning of gold rush regions, we should identify areas which become next target of mining, and to anticipate the extension of the contamination/damages. This sub-theme was to identify potential gold zones to base discussion of the vulnerability to the mercury contamination and to produce a set of two CD-ROMs to visualize the environmental planning. A set of introductory CD-ROMs was published in order (1) to enhance the basic datasets that were archived during the previous years, and (2) for them to be more effective for environmental management of gold mining, especially for small-scale mining.

(3) Estimation of mercury emission based on geological knowledge

Discharge and distribution of mercury are another important objects to understood characteristics of gold rush. A geological case study was performed in a gold mining area of northern Luzon Island, Philippines to calculate mercury discharge from small-scale gold mining. The mercury discharge from small-scale mining seems to be about two orders magnitude smaller than those of natural cycle and industrial activities[2] on the global scale. However it is large on local scale especially for each mining spot in gold rush regions[3]. It means that mercury discharge from small-scale mining could cause errors for the calculation of the total discharge if gold-mining contribution is not properly taken into consideration. Thus this sub-theme aimed at the precise analysis of environmental samples in a gold rush region and at understanding the situation of the contamination. Some artifacts such as soot in amalgamation huts were also examined as it is one of the major contaminants in gold rush regions.

The sub-theme also tried to express the mercury's diphasic distribution as a distribution coefficient K_d (cm^3/g, ratio of the concentrations between a solid and solution) under the assumption that river water and sediments attained a solid-water equilibrium.

$$K_d = \frac{[Hg]_{solid}(\mu g/g)}{[Hg]_{solution}(\mu g/cm^3)}$$

(4) Field investigation of mercury contamination and a trial of risk communication

This sub-theme included a characterization of mercury contamination from the viewpoint of human health and a risk communication study for the future trial of dialogue with miners. The characterization was to determine the mercury level in hair samples. The purpose of the risk communication study was to examine people's attitudes toward small-scale mining in the Philippines. Also a round table meeting was held in Tsukuba to draw lessons for risk communication between mineral property developers and local communities.

3. Methods

(1) Basic research on geochemical behavior of mercury

In order to observe mercury's fate in the environment, a gold mining region in Luzon island of the Philippines was selected. Field survey was done in dry season and water, sediments, soil, leaf litter and artifacts were collected. Artifacts are soot, ash, dust and tar-like material inside smelting places and represent an initial stage of the contamination[4]. Most samples were analyzed by CV-AFS for total mercury and methyl mercury, and some were analyzed by PIXE for total mercury.

For the improvement of the non-vacuum PIXE, the exit foil and backing foil materials were carefully selected and some kinds of ion species were tested for optimizing irradiation conditions. A new production method of homogenous backing foil was proposed[5]. The apparatus is to make a polyvinylformal film on a quartz-glass plate by drawing up the plate from PVF (2.5 %) dissolved tetrahydrofuran solution. Contaminated water samples from Cambodia were analyzed to check the detection efficiency of the improved method.

(2) Identification and mapping of potential gold zones

For the identification and mapping of potential gold zones, resource and geological information were collected from Cambodia, Laos, Vietnam, Thailand, and Myanmar during the fiscal year 2000. Then information on Brazil, Bolivia, Chile, Ecuador, Colombia, Paraguay, and Peru was collected in the fiscal year 2001. Topography, geology, tectonic structure, fault and lineament and related information were gathered. Additional background map data including major cities and hydrology data were taken from DCW (Digital Chart of the World) and World Data Bank II.

Then three categories of gold potential (A, B, C) have been defined for each gold zone to evaluate the attractiveness of the area to miners.

- Category A: Highest gold potential zone having existing gold deposit sites inside and with a radius 10-15 km.
- Category B: Intermediate gold potential zone having similar geologic criteria within 30 km and including several Category A area.
- Category C: Lowest gold potential zone that includes several Category B zones.

Based on the gold potential map of Cambodia, environmental sensitivity map was produced. For the production, the gold potential zones were converted to the environmentally vulnerable zones to the damage arising from gold rush by evaluating human factors which affect the environment such as mining method, trading route, and the distance to large cities.

The aforementioned datasets were imported to a GIS software package called TNTmips (developed by MicroImages, Inc., Lincoln, Nebraska, USA). Using the imported geospatial data, several map layouts representing gold occurrence distribution, and gold potential maps were made for each country. The geospatial data and layouts are hyper-linked using TNTmips to create special files which can then be browsed using TNTatlas. Next, the data and layouts were assembled in TNTatlas, a software package used to view the geospatial data and can be distributed free of charge.

(3) Estimation of mercury emission based on geological knowledge

A field survey was done in a gold rush zone around Baguio City of the Philippines (about 250 km from metro-Manila, north latitude 16.2o, east longitude 120.4o).

Stream sediments were filtered using the plastic container (diameter 0.4 μm, a Nalgen filter system) and air-dried. These dried sediments and soils were ground in a agate motor into 100 mesh, i.e. 74 μm, and were analyzed for the total mercury. Fifty-milliliter water samples were similarly filtered through the Nalgen filter system, and 0.5 cm^3 of concentrated nitric acid was added to acidify the samples for heavy metals. Total mercury analysis was carried out according to the JIS protocol on water and solid samples. It is based on Cold Vapor Atomic Absorption Spectrometry (CV-AAS) [6]. For artifacts, XANES and PIXE were applied for the chemical speciation.

(4) Field investigation of mercury contamination and a trial of risk communication

For the monitoring of human health, miners' hairs were collected and analyzed after getting their consent. The analysis was done by the PIXE at Iwate Medical University Cyclotron Center. This method was also applied to nails to enlarge the monitoring ability.

For the risk communication study, questionnaire sheets were distributed through convenient sampling method in the Municipality of Itogon in November 2002. A total of 228 questionnaires were recovered. The questionnaire contained the following questions.

a) impressions for various technologies and activities including nuclear power plant, small scale mining, traffic accidents, and so on.

b) risk perception

c) evaluation of countermeasures for mercury contamination caused by small-scale mining

d) evaluation of contribution in hazards and risks caused by small-scale mining.

e) evaluation of contribution in hazards and risks caused by large scale mining.
f) social value orientation scales proposed by Dake (1992)[7]

5. Results and discussion

(1) Basic research on geochemical behavior of mercury

Total mercury concentration obtained for unfiltered water from the study area varied from <5 to 500 ng/L while that for filtered water were < 5ng/L. Concentration of mercury for stream sediments ranged from < 0.007 to 1.865 ng/g and 1.18 to 2600 ng/g for methyl mercury and total mercury respectively. Leaf litters showed the total mercury values from 70.9 to 8670 ng/g and methyl mercury of 0.214 to 38.7 ng/g. The mercury concentration in soils ranged from 10 to 880 ppb. The total mercury concentration of artifacts showed the range from 42 ppm to 15.3 %.

According to the analyses this time, the background level of total mercury seems to be around 15 ng/g. Fourteen out of 17 samples are considered anomalous, i.e., 30-2600 ng/g. In general the distribution of total mercury and methyl mercury in stream sediments decreases downstream from possible source areas (smelting-living areas). Mercury contents are higher in stream sediments than soils

It seems that mercury contamination in gold rush region initiates as artifacts in smelting places and is diffused along streams and rivers through the transportation with suspending fine particles in water. Leaf litters are of great concern as methyl mercury source, and the estimation on the solubility of methyl mercury from leaf litters to water is a pressing need.

A new apparatus at Hiroshima University enabled the production of thin uniform PVF film ($2 - 20\ \mu g/cm^2$) with high reproducibility. In order to prevent the target from dropping-out from the backing foil and to keep the target's uniformity, small amount of diluted polyvinylacetate (PVAc) emulsion (200 ppm, 5 μ l) had to be added to the water samples. To maximize the ratio of characteristic X-ray intensities from low-Z elements to the continuum background X-ray intensities, the following combinations of ion and energy were necessary: 2 MeV hydrogen molecular ion for low-Z elements detection and 2 MeV proton for medium to high-Z elements detection.

After optimizing measuring conditions, we examined natural water samples from a gold mining village in Cambodia and found variety of the water. One of the samples was highly contaminated with heavy metals.

(2) Identification and mapping of potential gold zones

The CD-ROMs are composed of two discs, one is for Cambodia and the other for Latin America [8]. Figures 1 and 2 are sample screen snapshots for Cambodia. By clicking on one of the items listed at the lower right corner of this screen, the selected theme map is then displayed.

Users can superimpose other layers by switching "on and off" on the check boxes for the desired layers. For Latin America CD-ROM, a Country selection window was added.

Additional documents entitled "AboutThisCD.pdf" and "Install.pdf" (an installation guide) are included in the "Readme" folder of each CD-ROM. Informative research papers "Environmental Sensitivity Map of Cambodia," (Murao et al.), and "Mercury in Brazil," (Villas Boas) are included in "Metadata" folders along with metadata for the geospatial data contained on each of the CD-ROMs, respectively.

(3) Estimation of mercury emission based on geological knowledge

The total mercury concentration in soil and sediments varied from a maximum of 18 ppm to a minimum of 0.03 ppm. This finding is considered to be due to chemical / biological action received while transported from the source of discharge. Since the mercury content

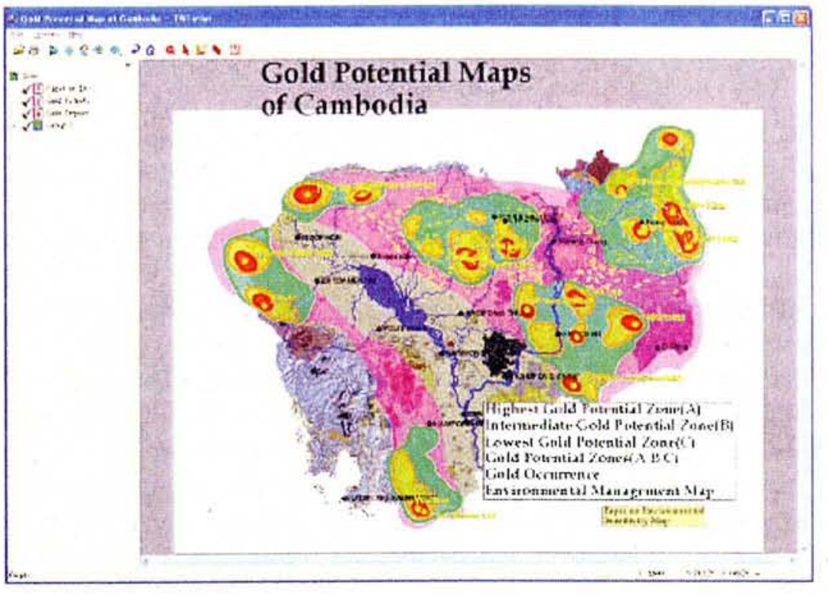

Fig. 1. The CD-ROM Startup screen for Cambodia.

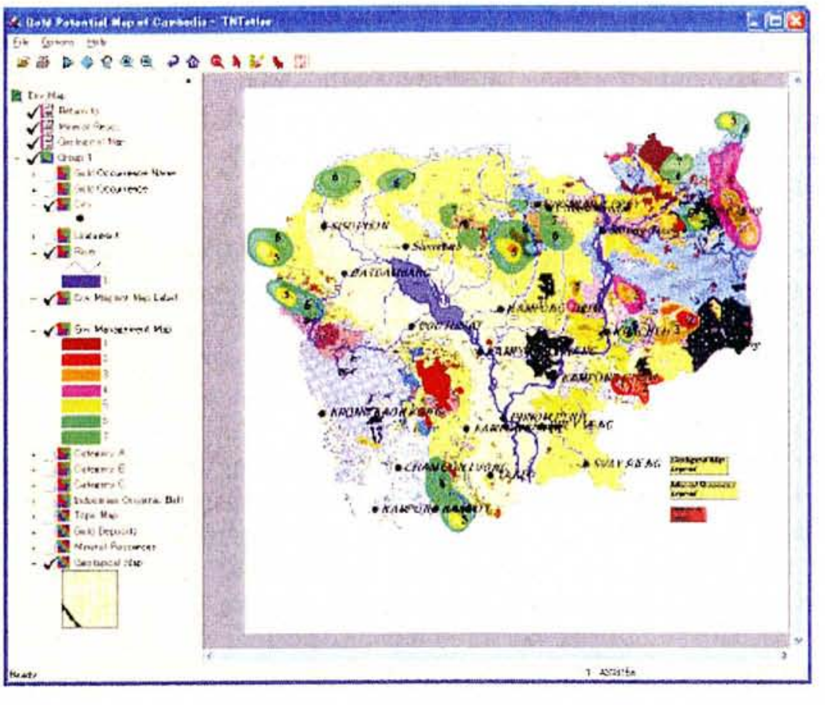

Fig. 2. Environmental Sensitivity Map of Cambodia.

in the rock and sediments which has not received artificial mercury pollution is on the order of 10 ppb, it is presumed that samples exceeding 0.1 ppm are mercury polluted. The soil and sediments of almost all sampling points are polluted with mercury on a remarkable level.

The total mercury concentrations in a water sample was 0.3 or less ppb level. It was thought that the total mercury concentration in drinking water currently used in the private house and near the elementary school were below the concentration which poses a health problem.

A great portion of mercury is incorporated into sediments and suspensions, and these sediments show big mercury adsorbability, so that the distribution coefficient of mercury is large. Therefore mercury in river water is removable only by filters like what used in this study.

pH values of river water were nearly the same for most sampling points, i.e., alkaline, 7-7.6. Moreover, these pH conditions showed the water environment is easier to adsorb, if mercury is an ionic nature. It is presumed that the main species in the river water are Hg^{2+} if Hg ion overcomes and sticks to competition with these coexisting cations such as Na^{+}, Ca^{2+}, etc.

The heavy metal in percolated river water (using the Nalgen filter system) were analyzed by the preconcentration PIXE method [9, 10]. Although the detected heavy metals are Mn, Fe, Ni, Cu, Zn, Zr, and As, any constituent was below the environmental standard. Arsenic concentration did not exceed ppb level. Under these pH conditions, it is presumed that the distribution of heavy metals from soil and sediment into water is small.

The PIXE spectrum (the polyethylene of 1000 μ m was used as an absorber) of soot extracted in the gold amalgam refinery showed that it contains Si, Ca, Sr, Ti, Mn, Fe, Cu, Zn, Hg, Pb, and Zr, and Hg. The mercury concentration of soot adhering to the ceiling was very high. The lead detected simultaneously with mercury may come from leaded fuel. In the PIXE spectrum of soot, Mg, Al, P, S, and K besides these elements were found. These will come from the soil constituents (aluminosilicates).

In order to investigate the chemical form of the mercury in this soot, X ray absorption edge structure was investigated. HgCl and $HgCl_2$ were used as the reference material, and soot (soot adhering to the ceiling, sample A, soot adhering to the wall, sample B) was measured on the same conditions. Although sufficient data to determine a chemical form are not obtained, near and sample B will be presumed to be close to the chemical state of $HgCl_2$ by HgCl for the mercury in sample A.

(4) Field investigation of mercury contamination and a trial of risk communication

This sub-theme indicated that the PIXE analysis is versatile in the detection of heavy elements in human hair. The system at Iwate Medical University was also effective to analyze nail samples [11]. A lot of hairs were analyzed and some specimens showed mercury anomaly [12]. In Mongolia, arsenic anomaly was found for several hairs. The maximum arsenic concentration was 3.3 ppm.

The risk communication study revealed the followings from the study of Itogon.

(A) Risk perceptions are relatively higher for nuclear weapons, terrorism, nuclear power plant, landslides, and mercury. On the contrary, risk perceptions are relatively lower for hiking, basketball, vaccination, hunting, and boxing. Unfamiliar risks such as nuclear weapons or nuclear power plants were evaluated high in risks, however, familiar risks such as sports were evaluated low in risks, the result being consistent with that of Slovic (1978)[13]

(B) Evaluations of countermeasures for reducing risks of mercury contamination by small-scale mining are shown in Table 2. Conducting effective public information dissemination by local governments was evaluated most highly compared to other countermeasures Introducing technological practices not to use mercury for small-scale mining by the government was also evaluated highly. In summary. interventions by government and companies were preferred countermeasures to alleviate mercury contamination. In particular, educational means were evaluated as effective.

(C) Evaluations of contribution to hazard or risks are shown Table 3.Two-tailed t-test were done for each pair of comparison. "*" in the table denotes significant differences. In large, contributions of small-scale mining in hazards and risks are evaluated smaller than those of large-scale mining. That is, small-scale mining was regarded as safer and to less impacting than large-scale mining. Although it is not true that small-scale mining is safer and has less impacts on the environment, people seem lenient to small-scale mining. On the contrary, people generally seem to have negative attitudes toward large-scale mining.

The round table meeting† was held on Jan. 14-15, 2003 in Tsukuba. The participants examined an experience for a mercury campaign in Amazon and confirmed the importance of relevant methodology to make people accept environmental ethics and plans. Other discussions can be summarized as follows.

(A) Mining companies are making efforts to establish their working moral as "best practice".

(B) Risk perception is different between mineral property developers and local people. But the difference has not enough analyzed and studied.

(C) Many mining companies and public organizations seem to look for a way to realize bilateral communication and dialogue. Regardless to the degree of awareness, they seem to practice risk communication in some cases.

Further study and analysis like what stated above could help developers and officers in charge of local society to consider the procedure to follow before a developmental plan begins and to cooperate people to make indigenous development plans.

Reference

1) S. Murao, V.B. Maglambayan and N. De La Cruz (editors): "*Small Scale Mining in Asia: Observations Towards a Solution of the Issue*" Mining Journal Books, London, 62 pp. (2002)

2) K. Marumoto, and M. Sakata : "Present Status of Research on Mercury in the Atmosphere", Geochemistry, **34**, 59-75 (2000)

3) H. Akagi, O. Malm, R. J. P. Branches, Y. Kinjo, Y. Kashima, J. R. D. Guimaraes, R. B. Oliveira, K. Haraguchi, W. C. Pfeiffer, Y. Takizawa, and H. Kato: "Human exposure to mercury due to gold mining in the Tapajos River Basin, Amazon, Brazil: speciation of mercury in human hair, blood and urine", Water Air Soil Poll., **80**, 85-94 (1995)

4) S. Murao, S. Futatsugawa, K. Sera, E. Clemente, L. Lanticse and V.B. Maglambayan: "Mercury content of amalgamation-related artifacts from small-scale mining sites in the Philippines", 6th ICMGP, Minamata (2001)

5) F. Nishiyama, T. Kikuchi and S. Murao:"Improved PIXE technique at Hiroshima University to detect light elements in water" Bull. Geol. Surv. Jpn. **51**, 485-494 ,in Japanese with English abstract (2000)

6) The Sediments Analysis Method II is derived. Reduction Evaporation Atomic Absorption Method; S46 Environment Agency Notification No. 59 Appended Chart 1.

7) K. Dake: "Myth of Nature: Culture and the Social Construction of Risk". Journal of Social Issues, **48**, 21-38, (1992)

8) S. Murao, E. Chaparro Avila, R. Villas Boas and T. Waza (editors):"*Gold Potential Maps for Environmental Management of Cambodia and Latin America*" CD-ROM, AIST 02-C00024 (2003)

9) M. Tsuji, K. Kawasaki, and T. Niizeki: "Rapid Monitoring of Industrial Wastewater by PIXE and Anion Chromatography", Int. J. PIXE **10**, 147-153 (2000)

10) M. Tsuji, K. Kawasaki, T. Niizeki, and M. Saitou: "Determination of Trace Elements in River Water Sample by PIXE", Int. J. PIXE **10**, 57-62 (2000)

11) K. Sera, S. Futatsugawa, S. Murao and E. Clemente: "Quantitative analysis of untreated nail samples for monitoring human exposure to heavy metals", Int. J. PIXE **12** (in print)

† Proceedings of the round table meeting is published as "Risk Communication Between Mineral Property Developers and Local Communities" from Mining Journal Books, London.

Table 1 Risk perception of local people in Itogon

Hazards and risks	Mean	SD
1.Alcoholic beverages	2.67	0.81
2.Radiation therapy	2.78	0.75
3.Small-scale mining	2.28	0.89
4.Coal/oil fired power plant	2.76	0.77
5.Crime	3.11	0.85
6.Economic crisis	3.00	0.90
7.Hiking as sports	1.65	0.69
8.Hunting as sports	1.83	0.73
9.Boxing as sports	1.93	0.71
10.Basketball	1.71	0.68
11.Car racing	2.68	0.78
12.Hydroelectric power plants	2.55	0.95
13.Mercury	3.02	0.78
14.Motorcycles	2.44	0.66
15.Terrorism	3.54	0.76
16.Nuclear weapons	3.59	0.72
17.Bicycles	1.93	0.65
18.Flying as airline passenger	2.26	0.66
19.Herbicide	2.41	0.68
20.Pesticide	2.62	0.72
21.Motor vehicles	2.20	0.60
22.Coal mining	2.47	0.75
23.Commercial aviation	2.30	0.64
24.Tractors	1.89	0.70
25.Food preservatives	2.12	0.77
26.Food colouring	2.18	0.76
27.Genetically modified food	2.16	0.72
28.Antibiotics	2.06	0.79
29.Nuclear power plant	3.33	0.84
30.Railroads	2.28	0.76
31.Water/ship transport	2.27	0.71
32.Vaccination	1.79	0.73
33.Large scale mining	2.95	1.61
34.Open pit mining	2.92	0.96
35.Underground mining	2.79	0.92
36.Mineral processing	2.59	0.83
37.Mine tailings dams	2.69	0.82
38.Open pit excavations	2.83	0.85
39.Mined-out areas	2.85	0.84
40.Land slides	3.09	0.75

Note : 4-point scale (very risky:4~not risky:1)

Table 2 Countermeasures to reduce risks of mercury contamination

Countermeasures	Mean	SD
1.Local governments to conduct effective public information dissemination	3.24	0.76
2.Local governments to create other job opportunity for local residents	2.87	0.88
3.Mining companies to employ local small-scale miners	2.92	0.84
4.National government to create other job opportunity for local residents	2.79	1.01
5.Mining companies to educate on hazards and handling of mercury	2.98	0.91
6.Local communities to prevent small-scale miners from using mercury in teir operations	2.53	1.03
7.Goverments to ban the use of mercury by small-scale miners	2.47	1.02
8.National government to tighten the regula tions on small scale mining	2.37	1.00
9.Local Government to tighten the regulations on small-scale mining	2.45	0.99
10.Government to introduce technological practices not to use mercury for small-scale mining	3.01	0.92
11.Goverment to regulate the importation of mercury to country	2.55	1.04
12.Goverment to ban the sale of mercury in small-scale mining communities	2.32	1.13

Note: 4-pont scale (4:very effective ~1:not effective)

Table 3 Contribution to hazards

Contribution	SSM	LSM
1.Subsisdence*	2.90	3.76
2.Water source depletion*	2.98	3.92
3.Deforestation*	3.01	3.96
4.River siltation*	3.08	4.02
5.River pollution*	3.16	4.02
6.Removal of vegetation cover*	2.87	3.75
7.Accidents*	2.90	3.49
8.Air pollution*	2.82	3.57
9.Noise pollution*	2.67	3.63
10.Forest fires*	2.59	3.06
11.Lung related diseases*	2.91	3.42
12.Prostitution*	2.08	2.75
13.Crime*	2.54	3.01
14.Alcohol problem*	2.90	3.32
15.Gambling*	2.84	3.27
16.Tax evasion	2.65	2.84
17.Illegal trading	2.62	2.70
18.Child labor*	2.49	3.59
19.Labour exploitation*	2.60	3.64
20.Corruption*	2.52	2.89
21.Labour practice violation*	2.13	3.10
22.Unnecessary migration	2.85	3.03
23.Local/ethnic relation problem*	2.65	2.99
24.Land ownership issues/problems	3.02	3.22

Note : Mean ratings of evaluations of contribution.
The greater the number is, the higher the contribution is.
SSM: small scale mining, LSM : large scale minimg.

(Reference: continued)

12) S. Murao, E. Daisa, K. Sera, V.B. Maglambayan and S. Futatsugawa: "PIXE measurement of human hairs from a small-scale mining site of the Philippines", Nucl. Instr. Meth. Phys. Res. **B189**, 168-173 (2002)

13) P. Slovic: "Perception of risk". Science, **236**, 280-285, (1987)