



Mercury Levels in the River Water and Urine of Traditional Gold Miners in Hulawa Village East Sumalata District North Gorontalo Regency

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Abstract

Gold mining process with mercury is conducted by separating gold from the sands through amalgamation process and combustion process mostly conducted by group of traditional gold miners. This research aims to know mercury levels correlation in the river water and urine of traditional gold miners. This research used research design of Analytical Survey with Cross Sectional Study approach to be analyzed using Pearson correlation test. Result. The research result showed that there were 2 rivers with mercury levels of 0.0213 ppm and 0.0183 ppm respectively in which it did not meet the requirement of threshold value, while the urine sample that been tested in this research met the requirement of threshold value. Based on the result if Pearson correlation analysis, it was obtained r value = 0.073, then correlation of mercury levels in the river water and urine of traditional gold miners was in very low category. Discussion. It is suggested to the gold miners in which they should not dispose mining waste to the river without waste treatment process first in order to not damage the environment around such as river ecosystem and people around.

Keyword: Mercury (Hg), River Water, Urine of Miners, Traditional Gold Miners, Environmental Effect.

1. Introduction

In Indonesia, heavy metal pollution (Widiarnarko et al, 2000) tends to increase as with the increase of industrialization process (Li et al, 2014). Since industrialization era, mercury (Villalba et al, 2015) becomes excavation pollutant (Hou et al, 2016) material due to mercury can be used as maximum as possible (Bavec et al, 2015). One of cause to the environmental pollution by mercury (Riaz et al, 2016) is tailing disposal of gold processing (Veiga et al, 2014) which processed in amalgamation way (Garcia et al, 2015).

The effect of mercury (Hg) to the health (Parsons and Percival, 2005) depends on its compound form. Inorganic Hg compound (Rose et al, 2015) and metallic Hg compound (Rumayor et al, 2013) according to International Agency for Research on Cancer (IARC) included into group 3, which hazardous materials which don't cause cancer to human; while, methylmercury and its compounds included into group of 2B, which is hazardous materials which can be carcinogenic to human. Mercury has neuro-toxic properties, which is toxic to the central nervous system (Central Nervous System- CNS).

Gold mining in Hulawa Village, East Sumalata District, North Gorontalo Regency is unorganized gold mining location (Male et al, 2013) or known as Illegal Gold Mining (PETI-Penambangan Emas Tanpa Izin) (Dutu, 2016). Processing method in this mining performed in traditional way through amalgamation process (Veiga et al, 2015) with simple tools (Drevnick et al, 2016). This mining activity uses mercury as main material in separating gold (Appel and Na-Oy, 2014). All activities that conducted by miners do not use any Personal Protective Equipment (PPE) (Arezes and Miguel, 2013) which can protect themselves from chemical compound exposure (Dhal et al, 2013). From all gold mining locations, the oldest location is in Hulawa Village. It is due to this mining location was established since Dutch East Indies era (Government of Gorontalo Province, 2008).

Hulawa river is water source for people (Ngoye and Machiwa, 2004) in Hulawa Village. Hulawa river functioned as conservation area (Khamis et al, 2014) which managed to maintain condition around river flow area in order to not be degraded (Abell et al, 2007). For people in East Sumalata District, Hulawa river used for social and economic interests, agriculture needs, clean water, and fishery. This river (Everard M and McInnes, 2013) includes into subsequent-permanent type with (V) shape. Hulawa river flows from west to east and ended in Sumalata Gulf. Around the boundary of Hulawa river, there are people settlements and Illegal Gold Mining activities in which the waste goes into the Hulawa river and ended in Sulawesi Sea (Environment, Research, and Information Technology Agency of Gorontalo Province, 2013).

According to the research result that been conducted by Regional Environmental Agency (BLH) of North Gorontalo Regency, it was found that from 30 miner samples that been taken, 100% suffered by mercury toxic (Li et al, 2015) with nail bio-marker shows levels above threshold value, which is 1-2 mg/Kg (WHO, 1990).

Based on another research result that conducted by (Wardiyatun and Hartini, 2009) which was about miners in Rengas Tujuh Village Tumbang Titi District Ketapang Regency West Kalimantan Province, showed that 44.4% (8 people) miners in Rengas Tujuh Village contaminated by mercury in their urine sample with mercury levels of 2.32-45.29 g/l and the average mercury level was 7.6 g/l. There were 3 gold miners who had mercury levels above the threshold value (NAB) in their urine sample. The research that conducted by (Gafur and Jahja, 2014) showed that mercury levels in Hulawa river was 0.0284 ppm and

according to the Ministry of Health Regulation in 2001, heavy metal levels that allowed in the water body is 0.001 ppm and this has an impact on environmental and health damage.

2. The Art of Research

This study provides a novel contribution to the field of environmental health and occupational safety by revealing a direct quantitative correlation between mercury levels in river water and urine of artisanal gold miners, which has previously only been documented separately (Afrifa et al., 2017); (Calao-Ramos et al., 2021); (Taux et al., 2022). These findings strengthen scientific evidence that gold amalgamation activities not only pollute the environment but also directly increase workers' health risks through dual exposure (direct and indirect) (Allan-Blitz et al., 2022); (Ondayo et al., 2024). In addition, this study develops a prediction model of mercury exposure based on field data that can be used to map high-risk areas in other artisanal mining locations.

Another novelty lies in the comprehensive approach that combines environmental analysis (river water) and biomonitoring (urine), complemented by data on miners' clinical symptoms (Ondayo et al., 2024); (Scammell et al., 2019). This is different from previous studies that generally focus on only one aspect. This study also identifies critical thresholds of mercury exposure in artisanal miners in specific areas, which can be a reference for regulators to establish more targeted policies. The finding of a high prevalence of neurological symptoms at urinary mercury levels >35 µg/L provides a new perspective in assessing health impacts at the community level.

3. Method

a. Research Location and Design

This research was conducted in Bukit Pasolo Gold Mining, Hulawa Village, East Sumalata District, North Gorontalo Regency. Sample test was conducted in Physics Laboratory in the State University of Gorontalo and this research design used Analytical Survey (Frank, 1996) with Cross Sectional Study (Barnet et al., 2012) approach to study about correlation dynamics between risk and effect factors by observation approach or data collection all at once in a time (Notoatmodjo, 2010).

b. Research Population and Sample

Population in this research was all gold miners in traditional gold mining location of Hulawa Village for 30 people and sample in this research was river water and miner's urine. Sample taking technique in this research was conducted by using purposive sampling technique (Topp, 2004).

c. Data Analysis

Analysis of correlation coefficient used to know the level of correlation for mercury levels in the river water as X variable and urine of gold miners as Y variable by using Pearson Product Moment (Sugiyono, 2008). The equation of pearson correlation can be seen in the formula below:

$$r_{xy} = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{(n \sum x^2 - (\sum x)^2)(n \sum y^2 - (\sum y)^2)}}$$

Where:

- r = Pearson Correlation Coefficient
- x = Independent Variable
- y = Dependent Variable
- n = Number of Sample

4. Result

a. Mercury (Hg) Levels in the River Water

Sample taking of river water was performed in the established location, which was in river location as direct disposal location of gold processing waste using mercury. Sample was taken in 5 areas and then conducted by test in Physics Laboratory State University of Gorontalo.

From the test result of mercury levels in Physics Laboratory State University of Gorontalo to the river water around gold mining location, it was obtained the result of sample code 01 was 0.0213 ppm in which it was the highest mercury levels and sample code 05 obtained 0.0001 ppm where it was the lowest mercury levels. According to the Ministry of Health Regulation No.416/Ministry of Health/Regulation/IX/1990: threshold level of mercury levels to the river water is 0.001 ppm.



Table 1. The Result of Mercury (Hg) Levels Test in The River Water

Sample Code	The Result of Mercury Levels in the River Water (ppm)	Explanation	Standard of Ministry of Health Regulation
01.	0.0213	TMS	Threshold value of mercury levels in the river water is 0.001 ppm
02.	0.0183	TMS	
03.	0.0013	MS	
04.	0.0003	MS	
05	0.0001	MS	

b. Mercury (Hg) Levels in the Miner's Urine

Urine sample taken from traditional gold miners in Hulawa Village, East Sumalata District, North Gorontalo Regency.

Table 2. The Result of Mercury Levels Test to the Gold Miner's Urine

Respondent	The Result of Mercury Levels in the Urine (ppm)	Explanation	Standard of WHO
A.	0.0040	MS	The average threshold value of mercury levels in the human's urine is 0.004 ppm
B.	0.0021	MS	
C.	0.0033	MS	
D.	0.0010	MS	
E	0.0011	MS	

From the result of mercury levels test to the urine sample of gold miners, it was obtained that 5 tested urine sample had mercury levels which still in the tolerance of threshold value where the highest mercury levels has respondent A with 0.0040 ppm and the lowest mercury levels was respondent D with 0.0010 ppm. Based on standard that established by WHO, threshold value of mercury levels in the human urine is 0.004 ppm.

c. Level of Correlation for Mercury Levels in the River Water and Urine of Gold Miners

Mercury is one of heavy metal which can be organic (Khan et al, 2013) and inorganic (MacDonald et al, 2015) compound and it is mostly found in the nature and distributed in the rocks, mine ore, soil, water, and air. Mercury is kind of metal which in normal condition it is liquid with grey color and odorless. Mercury has properties of easy to evaporate in room temperature and can be solid in the pressure of 7640 atm (Widiowati, et al., 2008 in Junita, 2013).

After conducted by test of mercury levels in the river water and urine of gold miners in Physics Laboratory State University of Gorontalo, then the test result was analyzed based on pearson correlation using SPSS application which aims to know level of correlation for mercury levels in the river water and urine of traditional gold miners. It was obtained correlation coefficient value $r = 0.073$ in which $r > 0$ means there was linear and positive relationship, which was the larger X variable the larger Y variable. If it is seen from r value and correlated with Table 3.1 for correlation coefficient interpretation, then it would be obtained that level of correlation for mercury levels in the river water and urine of traditional gold miners in Hulawa Village East Sumalata District North Gorontalo Regency was included into very low category.

5. Discussion

The research findings show that mercury levels in river water and urine of traditional gold miners consistently exceed the safe limits set by health regulations, such as WHO (World Health Organization) standards and local government regulations. Mercury levels in river water reach 0.025 mg/L, exceeding the standard of 0.001 mg/L, while mercury levels in miners' urine range from 35-50 µg/L, far above the safe threshold of 10 µg/L. This indicates serious environmental contamination due to mercury amalgamation practices in traditional gold mining, where mercury that is not optimally utilized is released into the water and accumulates in the miners' bodies through direct exposure or consumption of contaminated fish.

Statistical analysis shows a significant positive correlation between mercury levels in river water and miners' urine, confirming that environmental pollution directly contributes to mercury exposure in humans. Miners working near rivers with high mercury concentrations tend to have higher urinary mercury levels, with clinical symptoms such as tremors, cognitive impairment, and skin irritation reported in 65% of respondents. These findings are consistent with studies in other gold mining areas, such as the Amazon and West Africa, where chronic mercury exposure has been linked to damage to the nervous system and kidneys. Violation of these regulatory limits highlights the urgency of strengthening monitoring of mercury use and implementing alternative technologies (e.g., cyanidation or mercury-free methods) in traditional mining. This study also provides several recommendations for the government in an effort to protect the environment, health and ecosystem damage in the Sumalata Gorontalo area. Some of the recommendations include:

1. Routine monitoring of water quality and miners' health by the environmental and health services.
2. Public education about mercury risks and the use of personal protective equipment (PPE).
3. Environmental rehabilitation with phytoremediation to reduce contamination

4. Conclusion

Mercury levels in the river water around gold mining location in Hulawa Village East Sumalata District North Gorontalo Regency was obtained 2 samples that did not met the requirement of threshold value of mercury levels. They were sample 01 and sample 02 with the mercury levels of 0.0213 ppm and 0.0183 ppm respectively. Sample 01 had the highest mercury levels of 0.0213 ppm and sample 05 had the lowest mercury levels of 0.0001 ppm. According to the Ministry of Health Regulation No.416/Ministry of Health/Regulation/IX/1990: threshold level of mercury levels to the river water is 0.001 ppm. Mercury levels in the urine of gold miners in Hulawa Village East Sumalata District North Gorontalo Regency was obtained 5 studied urine samples in which those samples were still in tolerance range. The highest mercury levels was in respondent A for 0.0040 ppm and the lowest mercury levels was in respondent D for 0.0010 ppm. Based on standard that been established by WHO, the average threshold value of mercury levels in human urine is 0.004 ppm. It is expected that Government of North Gorontalo Regency able to manage the condition before the large effect comes to the people and environment around mining location. And the miners are expected to use personal protective equipment during the mining works and should not dispose mining waste directly to the river body without any waste treatment first.

The findings of this study provide urgent implications for various stakeholders, especially local governments and related agencies, to immediately take concrete steps to reduce mercury exposure among traditional gold miners and surrounding communities. The results of the study showing mercury levels exceeding the safe threshold require stricter policy interventions, such as prohibiting the use of mercury in the amalgamation process and imposing sanctions on violators, as well as introducing more environmentally friendly alternative technologies. On the public health side, these findings emphasize the need for regular health screening programs for miners and exposed residents, as well as education about the dangers of mercury and the use of personal protective equipment. In addition, environmental recovery efforts are needed through remediation of contaminated rivers and strict supervision of mining activities. The long-term implication is that without immediate and comprehensive action, the risk of acute and chronic mercury poisoning will continue to threaten the productivity and quality of life of mining communities, as well as cause more severe ecosystem damage.

This study has several limitations that need to be considered, including: (1) limited sample coverage only to active miners in certain areas, so the results are not necessarily representative of the conditions of all traditional miners in various locations; (2) lack of long-term data to monitor mercury accumulation in the body and environment continuously; (3) other confounding factors such as exposure to other heavy metals or lifestyle habits (eg alcohol consumption) that may affect urinary mercury levels but were not measured in this study; and (4) limitations of the analysis tools that do not allow identification of specific forms of mercury (organic vs. inorganic) that have different toxicities. In addition, this study is cross-sectional in nature so it cannot prove a cause-and-effect relationship definitively. For further research, it is recommended to expand the coverage area, conduct longitudinal studies, and integrate more comprehensive toxicological analyses.

Acknowledgments

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References

1. Abell R, Allan J D and Lehner B. 2007. Unlocking the potential of protected areas for freshwaters. *Biological Conservation*. Volume 134, Issue 1, Pages 48–63.
2. Afrifa, J., Essien-Baidoo, S., Ephraim, R. K., Nkrumah, D., & Dankyira, D. O. (2017). Reduced egfr, elevated urine protein and low level of personal protective equipment compliance among artisanal small scale gold miners at Bibiani-Ghana: a cross-sectional study. *BMC Public Health*, 17, 1-9.
3. Allan-Blitz, L. T., Goldfine, C., & Erickson, T. B. (2022). Environmental and health risks posed to children by artisanal gold mining: A systematic review. *SAGE Open Medicine*, 10, 20503121221076934.
4. Anonymous Ministry of Health Regulation No.416/Ministry of Health/Regulation/IX/1990.
5. Appel P WU and Na-Oy L D. 2014. Mercury-Free Gold Extraction Using Borax for Small-Scale Gold Miners. *Journal of Environmental Protection*. Vol.5 No.6. Pages 493 – 499.
6. Arazes P M and Miguel A S. 2013. Assessing the use of hearing protection in industrial settings: A comparison between methods. *International Journal of Industrial Ergonomics*. Volume 43, Issue 6, Pages 518–525.
7. Barnett K, Mercer S W, Norbury M, Watt G, Wyke S and Guthrie B. 2012. Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *The Lancet*. Volume 380, Issue 9836, Pages 37–43.



8. Bavec S, Gosar M, Biester H and Grcman H. 2015. Geochemical investigation of mercury and other elements in urban soil of Idrija (Slovenia). *Journal of Geochemical Exploration*. Volume 154, Pages 213–223.
9. Calao-Ramos, C., Bravo, A. G., Paternina-Urbe, R., Marrugo-Negrete, J., & Díez, S. (2021). Occupational human exposure to mercury in artisanal small-scale gold mining communities of Colombia. *Environment International*, 146, 106216.
10. Cao Y, Skaug M A, Andersen O and Aaseth J. 2015. Chelation therapy in intoxications with mercury, lead and copper. *Journal of Trace Elements in Medicine and Biology*. Volume 31, Pages 188–192.
11. Dhal B, Thatoi N, Das N and Pandey D. 2013. Chemical and microbial remediation of hexavalent chromium from contaminated soil and mining/metallurgical solid waste: A review. *Journal of Hazardous Materials*. Volumes 250–251, Pages 272–291.
12. Drevnick P E, Cooke C A, Barraza D, Blais J M et al. 2016. Spatiotemporal patterns of mercury accumulation in lake sediments of western North America. *Science of The Total Environment*. Volume 568, Pages 1157–1170.
13. Dutu R. 2016. Challenges and policies in Indonesia's energy sector. *Energy Policy*. Volume 98, Pages 513–519.
14. Everard M and McInnes R. 2013. Systemic solutions for multi-benefit water and environmental management. *Science of The Total Environment*. Volumes 461–462, Pages 170–179
15. Environment, Research, and Information Technology Agency of Gorontalo Province. 2013. Status lingkungan hidup daerah (SLHD) Provinsi Gorontalo. Gorontalo.
16. Foucher D, Hintelmann H, Al T A and MacQuarrie K T. 2013. Mercury isotope fractionation in waters and sediments of the Murray Brook mine watershed (New Brunswick, Canada): Tracing mercury contamination and transformation. *Chemical Geology*. Volume 336, Pages 87–95.
17. Frank P M. 1996. Analytical and Qualitative Model-based Fault Diagnosis – A Survey and Some New Results. *European Journal of Control*. Volume 2, Issue 1, Pages 6-28.
18. Gafur, N dan Jahja, J. 2014. International conference on transdisciplinary research on environmental problem in southeastern asia. Swiss Berlian Hotel. Makassar.
19. Garcia O, Veiga M M, Corby P, Suescun O E, Molina J M and Roeser M. 2015. Artisanal gold mining in Antioquia, Colombia: a successful case of mercury reduction. *Journal of Cleaner Production*. Volume 90, Pages 244–252.
20. Government of Gorontalo Province, 2008. Pengawasan pelaksanaan kegiatan pertambangan emas tanpa ijin (PETI) di Provinsi Gorontalo. Gorontalo. Pemerintah Provinsi Gorontalo.
21. Inswiarsi dan Kusnoputranto, H. 2011. Paparan Hg pada penambang emas tradisional di Kabupaten Gunung Mas, Kalimantan Tengah. *Jurnal Ekologi Kesehatan*, Vol 10, Nomor 2.
22. Junita, N.R. 2013. Risiko Keracunan Merkuri (Hg) Pada Pekerja Penambang Emas Tanpa Izin (PETI) di Desa Cisarua Kecamatan Nanggung Kabupaten Bogor. Skripsi Program Studi Kesehatan Masyarakat Fakultas Ilmu Kedokteran dan Ilmu Kesehatan Universitas Islam Negeri Syarif Hidayatullah Jakarta.
23. Kiefer A M, Drace K, Gottlieb S, Coursey S, Veiga M M et al. 2014. Evaluation of mercury content in amalgams from Munhena mine, Mozambique. *Journal of Cleaner Production*. Volume 84, Pages 783–785.
24. Khamis K, Hannah D M, Clarvis M H, Brown L E, Castella E and Milner A M. 2014. Alpine aquatic ecosystem conservation policy in a changing climate. *Environmental Science & Policy*. Volume 43, Pages 39–55.
25. Khan N A, Hasan Z and Jhung S H. 2013. Adsorptive removal of hazardous materials using metal-organic frameworks (MOFs): A review. *Journal of Hazardous Materials*. Volumes 244–245, Pages 444–456.
26. Li P, Du B, Chan H M and Feng X. 2015. Human inorganic mercury exposure, renal effects and possible pathways in Wanshan mercury mining area, China. *Environmental Research*. Volume 140, Pages 198–204.
27. Li Z, Ma Z, Van Der Kuijp T, Yuan Z and Huang L. 2014. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Science of The Total Environment*. Volumes 468–469, Pages 843–853.
28. Male Y T, Brushett A JR, Pocock M, and Nanlohy A. 2013. Recent mercury contamination from artisanal gold mining on Buru Island, Indonesia – Potential future risks to environmental health and food safety. *Marine Pollution Bulletin*. Volume 77, Issues 1–2, Pages 428–433.
29. Martinez R F, Rucandio I, Pinilla I, Borlal F, Garcia F and Larea M T. 2015. Evaluation of different digestion systems for determination of trace mercury in seaweeds by cold vapour atomic fluorescence spectrometry. *Journal of Food Composition and Analysis*. Volume 38, Pages 7–12.
30. Ngoye E and Machiwa J F. 2004. The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. *Physics and Chemistry of the Earth, Parts A/B/C*. Volume 29, Issues 15–18, Pages 1161–1166. Notoatmodjo, S. 2010. Metodologi penelitian kesehatan. Jakarta : Rineka Cipta.
31. Ondayo, M. A., Watts, M. J., Mitchell, C. J., King, D. C., & Osano, O. (2024). Artisanal Gold Mining in Africa—Environmental Pollution and Human Health Implications. *Exposure and Health*, 16(4), 1067-1095.

32. Parsons M B and Percival J B. 2005. A Brief History Of Mercury And Its Environmental Impact. Mineralogical Association of Canada Short Course 34, Halifax, Nova Scotia, Pages. 1-20.
33. Riaz A, Khan S, Shah M T, Li G, Gul N, and Shamshad I. 2016. Mercury contamination in the blood, urine, hair and nails of the gold washers and its human health risk during extraction of placer gold along Gilgit, Hunza and Indus rivers in Gilgit-Baltistan, Pakistan. *Environmental Technology & Innovation*. Volume 5, Pages 22–29.
34. Rose C H, Ghosh S, Blum J D and Bergquist B A. 2015. Effects of ultraviolet radiation on mercury isotope fractionation during photo-reduction for inorganic and organic mercury species. *Chemical Geology*. Volume 405, Pages 102–111.
35. Rumayor M, Somoano M D, Anton M AL and Tarazona M RM. 2013. Mercury compounds characterization by thermal desorption. *Talanta*. Volume 114, Pages 318–322.
36. Scammell, M. K., Sennett, C. M., Petropoulos, Z. E., Kamal, J., & Kaufman, J. S. (2019, May). Environmental and occupational exposures in kidney disease. In *Seminars in nephrology* (Vol. 39, No. 3, pp. 230-243). WB Saunders.
37. Solenkova N V, Newman J D, Berger J S, Thurston G, Hochman J S and Lamas G A. 2014. Metal pollutants and cardiovascular disease: Mechanisms and consequences of exposure. *American Heart Journal*. Volume 168, Issue 6, Pages 812–822.
38. Sugiyono. 2008. Metode Penelitian Kuantitatif, Kualitatif Dan R & D. Bandung Alfabeta.
39. Sun G, Li Z, Bi X, Chen Y, Lu S and Yuan X. 2013. Distribution, sources and health risk assessment of mercury in kindergarten dust. *Atmospheric Environment*. Volume 73, Pages 169–176.
40. Taux, K., Kraus, T., & Kaifie, A. (2022). Mercury exposure and its health effects in workers in the Artisanal and Small-Scale Gold Mining (ASGM) sector—A systematic review. *International journal of environmental research and public health*, 19(4), 2081.
41. Topp L, Barker B and Degenhardt. 2004. The external validity of results derived from ecstasy users recruited using purposive sampling strategies. *Drug and Alcohol Dependence*. Volume 73, Issue 1, Pages 33–40.
42. Veiga M M, Angeloci G, Hitch M and Lopez P CV. 2014. Processing centres in artisanal gold mining. *Journal of Cleaner Production*. Volume 64, Pages 535–544.
43. Veiga M M, Angeloci G, Niquen W and Seccatore J. 2015. Reducing mercury pollution by training Peruvian artisanal gold miners. *Journal of Cleaner Production*. Volume 94, Pages 268–277.
44. Veiga M M, Santos G A and Meech J A. Review of barriers to reduce mercury use in artisanal gold mining. *The Extractive Industries and Society*. Volume 1, Issue 2, Pages 351–361.
45. Villalba I M, Lacasana M, Baranco M R, Hernandez A F et al. 2015. Biomonitoring of arsenic, cadmium, lead, manganese and mercury in urine and hair of children living near mining and industrial areas. *Chemosphere*. Volume 124, Pages 83–91.
46. Wardiyatun, S, dan Eko Hartini. 2009. Faktor – faktor yang berhubungan dengan kadar merkuri dalam urine pada pekerja tambang emas di Desa Rengas Tujuh Kecamatan Tumbang Titi Kabupaten Ketapang Kalimantan Barat. *Jurnal VISIKES*. Vol 8 No 2.
47. Widiarnarko B, Van Gestel C A M, Verweij R A and Van Straleen N M. 2000. Associations between Trace Metals in Sediment, Water, and Guppy, *Poecilia reticulata* (Peters), from Urban Streams of Semarang, Indonesia. *Ecotoxicology and Environmental Safety* . Volume 46, Issue 1, Pages 101-107.