Journal of Environmental Science and Technology

ISSN 1994-7887

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Environmental Science and Technology
ISSN 1994-7887
DOI: 10.3923/jest.2018.254.261

Research Article
Effect of Mercury Contamination on the Diversity of Soil Arthropods in Poboya Gold Mining

Hasriyanty, Alam Anshary, Shahabuddin Saleh, Muhammad Basir-Cyio and Mohammad Yunus

Department of Agrotechnology, Faculty of Agriculture, Tadulako University, Palu, Central Sulawesi, Indonesia

Abstract
Background and Objective: Gold mining activities which use mercury have negative impacts on the diversity of soil arthropods. The present study aimed to analyze the diversity of soil arthropods in Poboya gold mining. **Methodology:** This study was an explorative descriptive analytical study. The research location was divided into 6 sampling points from the center of the gold mining area. One kilogram of soil was collected from every sampling point to analyze mercury, C-organic and nitrogen fiber contents of vegetation types. The sampling of soil arthropods used pitfall trap and core sampler. The analysis of difference of diversity, evenness, dominance and richness of arthropod species in every location used one-way ANOVA with level of significance $p<0.05$. **Results:** There were two classes of soil arthropods found, i.e., insecta and arachnida classes. Class insecta was the most dominant with 21,835 individuals from the total of 23,111 individuals. There was a negative correlation between the diversity of soil arthropods and mercury content of the soil. The higher the mercury contents in the soil, the lower the diversity of soil arthropods. Canonical correspondence analysis (CCA) showed that mercury content and vegetation types affected the diversity of arthropods in the mining areas (Km0, Km1, Km2) and nitrogen and C organic contents affected the diversity of arthropods in Km3, Km4 and Km5. **Conclusion:** Mercury contamination in the soil reduced the diversity of insect and arachnida classes arthropods in the gold mining area.

Key words: Arthropod diversity, class insect, class arachnida, mercury contamination, gold mining area

Citation: Hasriyanty, Alam Anshary, Shahabuddin Saleh, Muhammad Basir-Cyio and Mohammad Yunus, 2018. Effect of mercury contamination on the diversity of soil arthropods in poboya gold mining. J. Environ. Sci. Technol., 11: 254-261.

Corresponding Author: Alam Anshary, Faculty of Agriculture, Tadulako University, Palu, Central Sulawesi, Indonesia Tel: +62 811-4583-434

Copyright: © 2018 Hasriyanty *et al.* This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Land use change, especially agricultural lands, leads to reduced biodiversity[1]. Increased gold mining activities which use mercury in Indonesia, especially in Central Sulawesi, have caused agricultural land damage and reduced physical and chemical qualities of soil[2-4].

Mercury contamination in soil can change the physical, chemical and biological conditions of soil[5,6]. It also will affect soil biotas, including soil arthropods because mercury is also known as an active ingredient of synthetic pesticide which can kill insects, thus directly changing composition and community of soil arthropods[7-9].

There have been limited studies on the relationship between mercury content in the soil and diversity of soil arthropods[7]. Therefore, it is important to examine the relationship between mercury contamination of the soil and diversity of arthropods because changes of composition, species richness and diversity of soil arthropods will hamper the biological process of the soil as soil arthropods, including insects, collembola, mites, are the first decomposers destroying organic materials into small fragments to be decomposed further by bacteria or fungi.

This study aimed to analyze the diversity of soil arthropods in several levels of mercury contamination around Poboya gold mining area.

MATERIALS AND METHODS

Research type: The research was an explorative descriptive analytical study. The main focus of the study was the correlation between the level of mercury contamination in the soil and diversity of arthropods around Poboya gold mining. This study consisted of field research and laboratory research. The research location was determined purposefully (purposive sampling) by determining sampling points based on the data of previous research indicating that mercury contamination levels in the soil will gradually decrease the farther it is from Poboya goldmine[10].

The research location comprised 6 sampling points:

Km0 = The first location was an area 0 km from the center of the gold mining area (active tromol location; contamination level: highly contaminated)
Km1 = The second location was 1 km (contaminated) from the center of the mining area
Km2 = The third location was 2 km (slightly contaminated) from the center of the mining area
Km3 = The fourth location was 3 km from the center of the mining area
Km4 = The fifth location was 4 km from the center of the mining area
Km5 = The sixth location was 5 km (safe) from the center of the mining area

The sampling points in the field were determined using GPS (global positioning system).

Arthropod sampling:

- Soil arthropods were sampled in each research plot in two ways, i.e. pitfall trap and core sampler
- Sampling and extraction techniques referred to modified Standard Methods for Assessment of Soil Biodiversity and Land Use Practice[11]
- Pitfall trap was 7×10 cm plastic cup containing 70% alcohol filled 1/3 of it and detergent as necessary. It was plated in the ground until the surface was on the same level as the ground. Pitfall trap was set for 1×24 h. Iron sheet was installed above the pitfall to protect it from rain
- In every transect, there were 10 pitfall traps. After 24 h, the collected arthropods were taken and put in micro tubes containing 70% alcohol, to be taken to laboratory for identification
- Core sampler technique was used to collect arthropods in the ground. Core sampler was plastic tube with 5 cm diameter and 7 cm height. In every transect, there were 10 core samplers
- Soil sample was collected by pressing the tube onto the ground surface until the tube was level with the ground
- The collected soil sample was put in a cloth bag to maintain soil moisture and then taken to laboratory to be processed further using modified barlese tullgren
- All collected specimens were stored in micro tubes containing 70% alcohol

Supporting data observation: The observed supporting data included ground mercury level, nitrogen level, organic material and vegetation type and in each sampling location.

Arthropod identification: All arthropods collected from sampling were identified to species or morphospecies level for any unidentifiable sample. Identification was performed using arthropod identification book[12]. This study used two laboratories namely Laboratory of Plant Pests and Diseases of the Faculty of Agriculture and Laboratory of Agrotechnology Faculty of Agriculture, Tadulako University. This study was conducted for 8 months in 2017 from January-August, 2017.

Data analysis: Data analysis of species richness, abundance, dominance and evenness as well as diversity of soil arthropods used Shannon Wienner Index and Simpson Index. The relationships between various soil environmental factors such as soil mercury level, nitrogen level, organic material and vegetation, in affecting the diversity of arthropods were analyzed by Canonical Correspondence Analysis (CCA), while similarity of arthropod species in every location was analyzed by cluster analysis based on Morista similarity index. The entire analysis used PAST software.

The analysis of differences of diversity, evenness, dominance and species richness of arthropods in every location used one-way-ANOVA dan DUNCAN (DNMRT) with level of significance $p<0.05$.

RESULTS

The soil arthropods found in the present study consisted of two classes, i.e., Insecta and Arachnida. From the two classes, insecta was the most dominant with 21,835 individuals from the total of 23,111 individuals. There were 62 species from 28 families and 10 orders. Entomobrya sp1. is a species that was most commonly found at the mine site, which was 4,260 individuals and followed by *Solenopsis geminata* with 2,524 individuals (Table 1).

Table 1 also showed a trend that the further from the center of the mine, the higher the numbers of individuals, species and families. However, the number of the orders found tended to be similar in all sampling locations.

Further analysis showed that species richness, total individual, dominance, evenness and diversity of insects also decreased along with distance from the center of the mine. In the mine location (Km0), species richness and total individual were lower and significantly different from other locations while evenness was lower and dominance was higher. The diversity index was also lower in Km0 and different from other locations when using Shannon Wiener index, as well as Simpson index (Table 2).

Soil analysis showed that mercury level in the mining mine location was higher than that in locations further from the center of the mine (Table 3). There was a negative correlation between the diversity of soil arthropods and soil mercury content. The higher the mercury level in the soil, the lower the diversity of soil arthropods (Fig. 1). Besides mercury, there might had been other environmental factors which affected the diversity of soil arthropods. This was evident in multidimensional scaling analysis by Canonical Correspondence Analysis (CCA) which showed that mercury level and vegetation type affected arthropod diversity in mine locations (Km0, Km1 and Km2). Meanwhile, nitrogen and C organic contents affected arthropod diversity 3.4 and 5 km away from the mining location is the right term (Fig. 2).

Table 1: Class, order, family, species and total individual of every arthropod species by distance from gold processing location

Order	Family		Number species		Sampling points						
					Km0	Km1	Km2	Km3	Km4	Km5	Total
Class insecta											
1 Hymenoptera	1	Formicinae	1	*Camponotus* sp1.	0	13	0	0	0	55	68
			2	*Camponotus* sp2	0	3	2	4	3	0	12
			3	*Oechophylla smaragdina*	0	0	89	32	15	37	173
			4	*Paratrechina longicornis*	382	302	362	322	286	683	2337
	2	Ponerinae	5	*Diacamma rugosum*	0	8	36	20	9	90	163
			6	*Odontomachus* sp.	0	17	29	4	0	0	50
	3	Dolichoderinae	7	*Dolichoderus thoracicus*	0	16	0	12	8	12	48
			8	*Iridomyrmex*_sp1	0	22	0	0	0	88	110
			9	*Iridomyrmex*_sp2	0	11	25	5	11	54	106
			10	*Tapinoma melanocephalum*	11	0	12	5	410	186	624
			11	*Tapinoma* sp.	0	45	11	88	473	0	617
			12	*Technomyrmex* sp.	0	0	21	0	13	24	58
	4	Myrmicinae	13	*Monomorium floricola*	30	86	143	50	29	190	528
			14	*Monomorium* sp1.	0	25	8	0	0	0	33
			15	*Monomorium* sp2.	0	0	37	0	0	153	190
			16	*Oligomyrmex* sp.	0	0	22	0	0	5	27
			17	Pheidole_sp1	0	15	25	0	43	33	116
			18	Pheidole_sp2	*0*	0	0	0	9	53	62
			19	*Solenopsis geminata*	294	396	253	194	335	1052	2524
			20	*Tetramorium bicarinatum*	0	116	223	382	398	276	1395
			21	*Tetramorium* sp.	0	0	15	0	0	61	76
	5	Aenictinae	22	*Aenictus* sp.	0	0	0	135	105	153	393
	5	Aenictinae	22	*Aenictus* sp.	0	0	0	135	105	153	393

Table 1: Continue

Order	Family		Number species		Km0	Km1	Km2	Km3	Km4	Km5	Total
					Sampling points						
	6	Cerapachyinae	23	*Cerapachys* sp.	0	0	0	110	111	128	349
	7	Pompilidae	24	*Priocnemis* sp.	0	53	173	0	0	43	269
	8	Encyrtidae	25	Encyrtidae sp1.	0	18	11	52	77	31	189
	9	Reduviidae	26	Reduviidae sp1.	15	27	65	0	32	0	139
2 Coleoptera	10	Carabidae	27	*Amara* sp.	20	19	0	36	0	0	75
			28	*Carabaidae* sp1	0	18	27	12	2	0	59
			29	*Carabidae* sp2.	5	10	9	31	0	11	66
	11	Scarabaeidae	30	*Clivina* sp.	23	14	41	0	21	0	99
3 Diptera	12	Sciaridae (agas)	31	*Sciara* sp.	0	15	47	28	21	39	150
	13	Cecidomyiidae	32	*Lestremia* sp.	0	22	85	0	0	104	211
	14	Muscidae	33	*Musa domestica*	31	42	49	0	21	0	143
4 Hemiptera	15	Cicadidae	34	*Tibicen* sp. (nymph)	0	19	25	71	22	0	137
	16	Aphididae	35	*Aphis fabae*	18	28	56	41	17	32	192
5 Dermaptera	17	Cacinophorida	36	*Chelisoches* sp.	1	21	0	0	0	77	99
6 Orthoptera	18	Gryllidae	37	*Allonemobius* sp.	0	52	158	10	0	49	269
7 Isoptera	19	Rhinotermitidae	38	*Captotermes* sp1	14	5	23	128	0	145	315
			39	*Captotermes* sp2.	0	15	16	19	32	57	139
8 Collembola	20	Entomobryidae	40	*Entomobrya* sp1.	529	421	589	857	878	986	4260
			41	*Entomobrya* sp2.	0	21	40	89	129	247	526
			42	*Entomobrya* sp3.	12	0	120	147	48	187	514
			43	*Entomobrya* sp4.	0	73	69	49	109	54	354
			44	*Lepidocyrtus* sp.	12	27	12	20	0	123	194
			45	*Coenalestes* sp12.27	22	12	11	137	102	85	369
			46	*Pogognatelus* sp.	0	10	21	8	23	0	62
			47	*Homidia* sp.	0	23	65	22	0	12	122
	21	Isotomiidae	48	*Isotoma viridis*	24	99	145	87	82	122	559
			49	*Isotoma* sp.	8	29	80	50	64	68	299
			50	*Folsomia candida*	11	58	65	25	34	69	262
	22	Neanuridae	51	*Anurida granaria*	0	34	124	98	103	173	555
	23	Hypogastruidae	52	*Podura acuatica*	0	48	92	71	0	71	282
			53	*Hypogastura* sp.	38	77	95	26	45	49	330
			54	Ceratophysella	0	0	29	11	22	59	121
			55	Unidentified	20	25	99	94	12	0	250
9 Diplura	24	Japygidae	56	*Metajapyx* sp.	0	21	43	0	79	23	166
Class arachnida											
10 Araneae	25	Oxypidae	57	*Pordosa* sp.	0	0	0	0	22	105	127
	26	Salticidae	58	*Cormophasis* sp.	8	0	0	31	0	89	128
	27	Loxoscelidae	59	*Loxosceles* sp.	34	12	105	74	21	45	291
	28	Acari	60	*Diaptorebates notatus*	20	42	75	112	110	122	481
			61	*Tetranychus* sp.	0	12	22	8	22	0	64
			62	Unidentified	17	0	11	65	68	24	185
Number of individual (Class Insecta)					1520	2431	3797	3582	4233	6249	21835
Number of individual (Class Arachnida)					79	66	213	290	243	385	1276
Total individual					1599	2497	4010	3872	4476	6634	23111
Number of orders					8	10	8	8	8	10	
Number of families					14	21	19	14	18	20	
Number of species					25	48	52	45	44	49	

Table 2: Species richness, total individual, dominance, evenness and diversity arthropod in all sampling point from the center of poboya gold mining area

Parameters	0	1	2	3	4	5
	Sampling point (km)					
Species richness	25^{a}	48^{b}	52^{c}	45^{c}	44^{bc}	49^{d}
Total individual	1,599^{a}	2,497^{a}	4,010^{ab}	3,872^{b}	4,476^{b}	6,634^{c}
Dominance index	0.27^{a}	0.14^{b}	0.082^{c}	0.11^{bc}	0.11^{bc}	0.08^{c}
Evenness Index	0.60^{a}	0.66^{ab}	0.75^{b}	0.60^{a}	0.63^{a}	0.60
Shannon-wiener diversity index	1.67^{a}	2.37^{b}	2.77^{cd}	2.64^{bc}	2.55^{bc}	2.92^{d}
Simpson diversity index	0.73^{a}	0.86^{b}	0.91^{c}	0.88^{bc}	0.88^{bc}	0.91^{c}

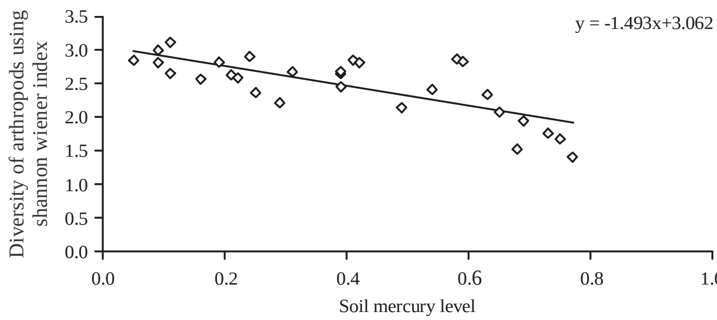

Fig. 1: Linear regression showing the relation between soil mercury level and diversity of arthropods using Shannon Wiener Index → Nilai regression coefficient (R^2)

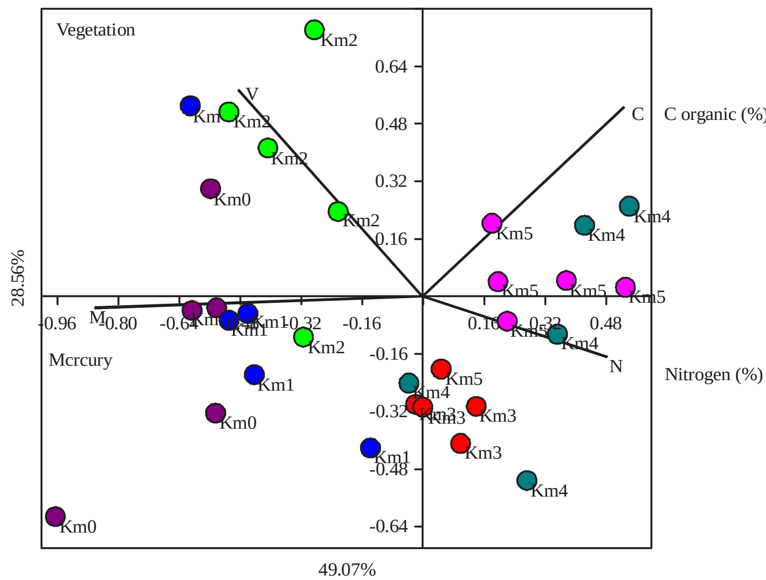

Fig. 2: Canonical correspondence analysis (CCA) diagram showing the effects of various environmental factors on the diversity and abundance of soil arthropods in different distances from the center of the mine

Table 3: Analysis results of mercury, nitrogen, c organic contents of soil and vegetation diversity in every arthropod sampling point

	Environmental parameters			
Sampling points	Mercury (mg L^{-1})	Nitrogen (%)	C organic (%)	Vegetation diversity*
Km0	0.73	0.08	0.91	4.2
Km1	0.58	0.16	1.44	8.0
Km2	0.42	0.21	2.62	12.8
Km3	0.26	0.21	2.01	5.4
Km4	0.21	0.18	2.04	4.6
Km5	0.11	0.21	2.32	5.6

Figure 3 confirmed that mercury contamination in the soil strongly affected the diversity of soil arthropods. Arthropod diversity 5 km (Km5) away from the center of the mine or location with low mercury level clustered separately, while locations 1-4 km (Km1, Km2, Km3, Km4) away from the center of the mine had similarities with arthropods in the mine location (Km0).

DISCUSSION

Gold processing activities which use mercury in the amalgamation process in Poboya goldmine is the main source of pollutant of the soil around the mine. It has high mercury contamination which exceeds the safety threshold. Soil analysis in the sampling locations showed that the soil

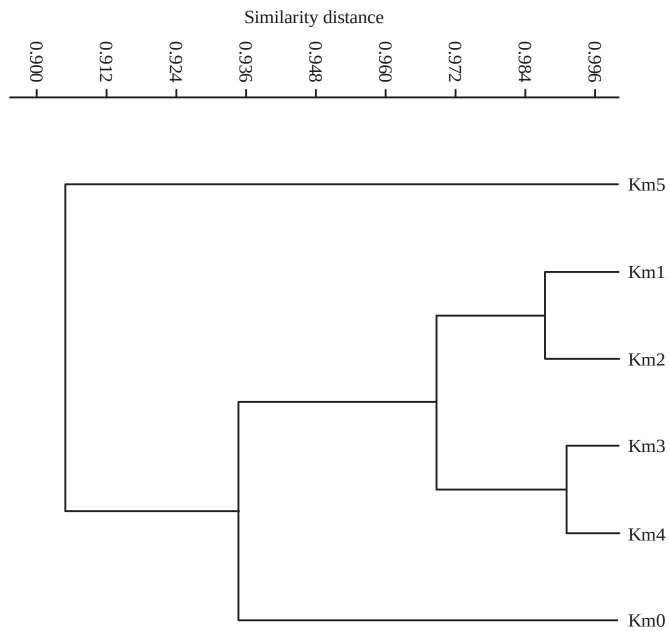

Fig. 3: Cluster analyses of arthropods by distance from the center of the mine

Cluster I : Km0 = The first location was an area 0 km from the center of the gold mining area (active tromol location; contamination level: highly contaminated), Cluster II: Km1 = The second location was 1 km (contaminated) from the center of the mining area, Km2 = The third location was 2 km (slightly contaminated) from the center of the mining area, Km3 = The fourth location was 3 km from the center of the mining area, Km4 = The fifth location was 4 km from the center of the mining area, Cluster III: Km5 = The fifth location was 5 km (safe) from the center of the mining area

mercury levels were 0.05-0.77 mg kg^{-1}, exceeding 0.01 mg kg^{-1} of soil. The same thing is reported by Sari *et al.*[10] and Mirdat *et al.*[4]. Leiva and Morales[13] and Luo *et al.*[14] also reported that gold mining activities which use amalgamation technology are sources of mercury contamination of the soil.

Mercury contamination in the ground can last a long time because it can be bound with other elements to create new compounds which remain toxic or even more toxic and dangerous to life, e.g., organic mercury methylmercury[15-17]. The formation of methylmercury was caused by bacterial activities, but it was reported that termites can also methylate mercury into methylmercury[18].

Several species of soil arthropods can live or tolerate soil with high mercury level, especially ground-surface arthropods[19]. However, from 62 species found, only several species from the family formicidae (ant) and family entomobryidae (Collembola) were found in abundance in the mining location. *Paretrecina longicornis*, *monomorium floricola* and *Solenopsis geminata* ants were collected in large numbers. The presence of the three ant species in high soil mercury level showed that they have high adaptability compared to other ant species. A study by Hasriyanty *et al.*[20] showed that the three ant species can be found in habitats contaminated by mercury.

Another arthropod species found in abundance was collembola. There were 16 species from the order of collembola which were found and 10 of them were found in the mining location. However, only one species from the family entomobryidae was found in abundance. The high number of collembola species found might be because the species have high adaptability and tolerance to mercury contamination or because there were many species with different roles in the ecosystem. Besides the family entomobryidae, some species from the family isotomiidae and hypogastruidae were also found in the mine location.

The effects of mercury on arthropods, particularly insects, are often used to study bioaccumulation process on terrestrial insects. Some of them are toxicology effects on *Locusta migratoria* (Coleoptera: Acrididae)[21], *Folsomia candida* and *Proisotoma minuta* (Collembola: Isotomidae)[7]; as well as *Blatella germanica* (Blattaria: Blattellidae)[22]. It has been reported that in sicada, bioaccumulation of mercury in male insects is higher than that in female insects[23,24].

This study has shown that gold mining activities reduce the diversity of soil arthropods. Thus, it can be proposed that rehabilitation is needed to reduce mercury pollution in the mining area. One alternative is the bioremediation by planting multiplying plants that can accumulate mercury to the soil. Isrun *et al.*[3] showed that the tithonia diversifolia compost can be used for the recovery of agricultural land and plants contaminated by Hg^{2+}. This study has a limitation that is the wide range of the observation areas.

CONCLUSION

Based on the findings, it can be concluded that mercury contamination in the soil reduced the diversity of soil arthropods. There was a correlation between the diversity of arthropods and soil mercury content. The closer to the center of the mine (higher soil mercury level), the lower the diversity of arthropods. From 62 species found, only 25 species were collected from the gold mining area.

SIGNIFICANCE STATEMENT

This study indicates that mercury usage in gold mining activities reduced classes of insecta and arachnida arthropods. This study will help the researchers uncover critical areas of soil arthropod types which can live or are tolerant to soil with high level of mercury contamination, especially ground-surface arthropods. Thus, the high mercury level of soil showed that ant species of *Paratrecina longicornis*, *Monomorium floricola* and *Solenopsis geminata* have a high adaptability level.

ACKNOWLEDGMENTS

This article is a part of Doctoral Dissertation Research funded by the Ministry of Research, Technology and Higher Education, Directorate General of Research and Development Reinforcement in accordance with Grant Implementation Agreement for Doctoral Dissertation Research Program. The authors would like to thank the Directorate General of Research and Development Reinforcement for funding the dissertation research. The authors also thank all parties who helped completing this study.

REFERENCES

1. Elhayati, N., A. Hariri, L. Wibowo and Y. Fitriana, 2017. Soil surface arthropod diversity in cassava (*Manihot utilissima* pohl.) after tillage and weed management. J. Agrotek. Trop., 5: 154-164.
2. Basir-Cyio, M., Mahfudz, T. Inoue, A. Anshary and T. Kawakami *et al*., 2017. Impact of the traditional gold mine management on public health and agricultural land: A Study of traditional gold mining in Poboya, Sausu and Dongi-Dongi Village, Central Sulawesi, Indonesia. J. Food Agric. Environ., 15: 115-122.
3. Isrun, M. Basir-Cyio, I. Wahyudi, U. Hasanah, S. Laude, T. Inoue and T. Kawakami, 2018. *Tithonia diversifolia* compost for decreasing the activity of mercury in soil. J. Environ. Sci. Technol., 11: 79-85.
4. Mirdat, Y.S. Patadungan and Isrun, 2013. The level of heavy metal of mercury (Hg) in soil of agricultural area around gold mining in Poboya, Palu. e-J. Agrotekbis, 1: 127-134.
5. Chibuike, G.U. and S.C. Obiora, 2014. Heavy metal polluted soils: Effect on plants and bioremediation methods. Applied Environ. Soil Sci., Vol. 2014. 10.1155/2014/752708
6. Tchounwou, P.B., C.G. Yedjou, A.K. Patlolla and D.J. Sutton, 2012. Heavy Metal Toxicity and the Environment. In: Molecular, Clinical and Environmental Toxicology, Luch, A. (Ed.)., Vol. 3, Springer, Basel, Switzerland, pp: 133-164.
7. Buch, A.C., J.C. Niemeyer, M.E.F. Correia and E.V. Silva-Filho, 2016. Ecotoxicity of mercury to *Folsomia candida* and *Proisotoma minuta* (Collembola: Isotomidae) in tropical soils: Baseline for ecological risk assessment. Ecotoxicol. Environ. Safety, 127: 22-29.
8. Odumo, B.O., G. Carbonell, H.K. Angeyo, J.P. Patel, M. Torrijos and J.A.R. Martin, 2014. Impact of gold mining associated with mercury contamination in soil, biota sediments and tailings in Kenya. Environ. Sci. Pollut. Res., 21: 12426-12435.
9. Ramlal, P.S., F.W.B. Bugenyi, G.W. Kling, J.O. Nriagu, J.W.M. Rudd and L.M. Campbell, 2003. Mercury concentrations in water, sediment and biota from lake victoria, East Africa. J. Great Lakes Res., 29: 283-291.
10. Sari, M.M., T. Inoue, Y. Matsumoto, K. Yokota and Isrun, 2016. Assessing a mercury affected area from small-scale gold mining in Poboya, Central Sulawesi, Indonesia. Environ. Ecol. Res., 4: 223-230.
11. Swift, M. and D. Bignell, 2001. Standard methods for assessment of soil biodiversity and land use practice. International Centre for Research in Agroforestry, Bogor, Indonesia.
12. Heckman, C.W., 2010. Encyclopedia of South American Aquatic Insects. Springer, Netherlands.
13. Leiva, M.A.G. and S. Morales, 2013. Environmental assessment of mercury pollution in urban tailings from gold mining. Ecotoxicol. Environ. Safety, 90: 167-173.
14. Luo, W., Y. Lu, B. Wang, X. Tong and G. Wang *et al*., 2009. Distribution and sources of mercury in soils from former industrialized urban areas of Beijing, China. Environ. Monitor. Assess., Vol. 158. 10.1007/s10661-008-0600-3
15. Ahern, N., 2016. Mercury in Gold Processing. In: Gold Ore Processing, Adams, M.D. (Ed.)., Elsevier, Paris, pp: 753-766.
16. Hidayati, N., T. Juhaeti and F. Syarif, 2009. Mercury and cyanide contaminations in gold mine environment and possible solution of cleaning up by using phytoextraction. Hayati J. Biosci., 16: 88-94.

17. Robles, I., J. Lakatos, P. Scharek, Z. Plank and G. Hernandez, 2014. Remediation of Soils and Sediments Polluted with Mercury: Occurence, Transformations, Environmental Consideration and San Joaquin's Sierra Gorda Case. In: Environmental Risk Assessment of Soil Contamination, Soriano, M.C.H. (Ed.)., InTech, Croatia, pp: 827-850.
18. Limper, U., B. Knopf and H. Konig, 2008. Production of methyl mercury in the gut of the Australian termite *Mastotermes darwiniensis*. J. Applied Entomol., 132: 168-176.
19. Janssens, T.K.S., D. Roelofs and N.M. Van Straalen, 2009. Molecular mechanisms of heavy metal tolerance and evolution in invertebrates. Insect Sci., 16: 3-18.
20. Hasriyanty, A. Rizali and D. Buchori, 2015. Ant diversity and its presence pattern in Urban areas in Palu, Central Sulawesi. J. Entomol. Indones, 12: 39-47.
21. Martoja, R., J.M. Bouquegneau and C. Verthe, 1983. Toxicological effects and storage of cadmium and mercury in an insect *Locusta migratoria* (Orthoptera). J. Invertebrate Pathol., 42: 17-32.
22. Zhang, Y., S. Lambiase, M. Fasola, C. Gandini, A. Grigolo and U. Laudani, 2001. Mortality and tissue damage by heavy metal contamination in the German cockroach, *Blattella germanica* (Blattaria, Blattellidae). Italian J. Zool., 68: 137-145.
23. Heckel, P.F. and T.C. Keener, 2007. Sex differences noted in mercury bioaccumulation in *Magicicada cassini*. Chemosphere, 69: 79-81.
24. Zhang, Z., X. Song, Q. Wang and X. Lu, 2012. Mercury bioaccumulation and prediction in terrestrial insects from soil in Huludao city, Northeast China. Bull. Environ. Contam. Toxicol., 89: 107-112.