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Ecological and Health Risks of Heavy Metals to the Residents affected by a Volcanic Eruption in the Philippines

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ABSTRACT

Volcanic eruption can be a source of heavy metal contamination and such contamination may cause certain risks to the environment and to those who are exposed to the volcanic contents. This study aimed to determine the ecological and health risks from heavy metal exposure in the soil after a volcanic eruption. The agricultural soil samples were collected from Cuenca and Talisay, Batangas and Tagaytay City, Cavite, and were processed for arsenic, cadmium and mercury detection and quantification. The detected metal concentrations were compared to the standard values of the Department of Environmental and Natural Resources for arsenic and United States Environmental Protection Agency for cadmium and mercury while the ecological and human health risks were assessed by computing for the potential ecological risk, hazard quotient and hazard index, respectively. Arsenic was the only heavy metal with high mean concentration in the soil samples of Talisay, Batangas and Tagaytay City, Cavite while cadmium and mercury in the soil were within the acceptable level in the three municipalities. The soil from Talisay, Batangas had two-fold arsenic increase while the samples from Tagaytay City, Cavite had one-fold arsenic elevation. The soil's post-volcanic eruption's arsenic contamination was probably due to the direction of the wind during the eruption and groundwater contamination. Low ecological risk and no human health risk were observed despite the recent arsenic concentration in the soil. A two-fold increase in arsenic concentration in the soil will not yet cause ecological and human health risk.

INTRODUCTION

Volcanic eruption as a source of heavy metals is less recognized than anthropogenic sources since it is less commonly observed and experienced. Volcanic eruptions caused deleterious effects on humans and the environment, such as burns, respiratory problems, destruction of houses and buildings and damaged crops (Horwell *et al.*, 2020). The gases from a volcanic eruption and the elements in the volcanic ash may contaminate the environment and subsequently affect the health of living organisms. Acid rain is usually observed during and after a volcanic eruption. Its acidity promotes plant uptake of metals (Kim *et al.*, 2010; Jenkins *et al.*, 2015). Most of the local studies about heavy metals in the environment are related to anthropogenic sources (Buagas *et al.*, 2024; Cortez & Ching, 2014). Due to the limited local studies about the assessment of heavy metals after a natural calamity, the study aimed to determine the potential ecological and human health risks from heavy metal exposure in the soil of the municipalities that were affected by Taal Volcano eruption.

LITERATURE REVIEW

The ashes contain several heavy metals that may alter the normal growth and development of crops and animals. It may even accumulate in these organisms and may affect the food chain. Cadmium, mercury, arsenic and lead were detected in the environment. They can be ingested and taken up by fishes and other living organisms. Increasing

environmental concentration of these heavy metals contributes to the accumulation and transfer in the food chain (Martinez *et al.*, 2011).

The common routes of entry of heavy metals in the human body are through the inhalation, ingestion and skin penetration (WHO, 2007). Mercury, lead, cadmium and arsenic are the known toxic heavy metals. Mercury has several forms and each form has its own modes of entry in the body. Elemental mercury is the vapor form that may gain access to the brain and kidneys after its initial injury to the respiratory system. Inorganic mercury is the metallic mercury that mainly accumulates in the kidneys. Methylmercury is the most significant form of mercury since it may cause illness through any of the following routes: inhalation, ingestion and skin penetration (ATSDR, 1999). Aside from mercury, arsenic is also a toxic heavy metal that causes health effects after its ingestion. Its acute effects are mainly gastrointestinal manifestations such as difficulty in swallowing, vomiting and organ injury. In chronic arsenic exposure, carcinogenic effects are observed in the skin, lungs, kidneys and bladder (US EPA, 2001). Another metal that affects gastrointestinal tract is cadmium. Cadmium may cause gastrointestinal and/or neurologic symptoms when an individual ingests contaminated vegetables and foods (Sharma *et al.*, 2015). Respiratory and renal problems are also detected in individuals with exposure to cadmium. Prolonged cadmium exposure may even lead to cancer since its biological half-life is 30 years (ATSDR, 1990).

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In the Philippines, provinces with significant heavy metal exposure are those that are exposed to mining industries (BanToxics, 2011). Aside from anthropogenic activities, heavy metal exposure after volcanic eruption should also be performed to determine the level of pollutant contamination after the calamity.

MATERIALS AND METHODS

This study evaluated the ecological and health risks from exposure to mercury, arsenic, and cadmium after the 2020 Taal volcanic eruption. The soil samples were collected from seven locations in Talisay, Batangas, six locations in Tagaytay City, Cavite and one location in Cuenca, Batangas. The latter has the least number of collection sites for soil assessment since it represented the municipalities that are less affected by the 2020 Taal volcano eruption. The soil samples were collected from either the garden or backyard of the house of a resident. A total of 1,000 grams of soil were collected in each location from an approximate depth of 10cm. The samples were placed in a properly labelled polyethylene bag containers. Three replicate soil samples were collected from each location and were sent to a laboratory for processing and quantification of mercury, arsenic and cadmium. The soil samples were stored at room temperature and were dried prior to its processing in a laboratory. The soil samples was processed and underwent cold vapor atomic absorption spectrometry for mercury detection and quantification while Manual hydride generation Atomic absorption spectrophotometry (AAS) and direct air-acetylene flame were used in the detection and measurement of arsenic and cadmium in the soil samples, respectively. The results were presented in mean concentration.

Mathematical Expressions and Symbols

Ecological Risk Assessment

The geoaccumulation index, enrichment factor and potential ecological risk index were used in assessing the ecological risk in the polluted soil.

The geoaccumulation index (I_{geo}) was used to determine

the degree of heavy metal pollution or contamination in the agricultural soil (Muller 1969). It was computed using this equation

$$I_{geo} = \log_2 (C_n / 1.5 B_n)$$

where C_n refers to the estimated concentration of heavy metals n and B_n as the background value in the soil. The background values in the soil were based on DENR AO2019-17 standard values for arsenic and based on the local studies of Posadas *et al.* (2022) and Nolos *et al.* (2022) for mercury and cadmium concentration and it is as follows: mercury=2.19 ppm, arsenic=2.0 ppm and cadmium=0 ppm.

Meanwhile, the enrichment factor (EF) was also determined, and was identified the degree of metal enrichment in the soil- from natural or anthropogenic activities. It was computed using this equation (Barbieri 2016):

$$EF = (Metal/RE)_{soil} / (Metal/RE)_{background}$$

where RE refers to the value of reference element based on DENR AO 2019-17 standard values for arsenic and the cadmium and mercury concentration of a local study. An EF value of <2 indicated deficiency to minimal enrichment, 2<EF<5 signified moderate enrichment, 5<EF<20 was interpreted as significant enrichment, 20<EF<40 indicated very high enrichment and EF>40 extremely high enrichment.

Since this study has detected a single element in the soil, potential ecological risk factor for a specific element was computed but not the potential ecological risk index. The computation and toxic response factor were based on Hakanson (1980) using the following equation:

Potential ecological risk factors (E_r^i) for a specific element $E_r^i = Tr^i \times C_f^i$

where E_r^i , potential ecological risk factor for a specific heavy metal i , were computed using the toxic response factor Tr^i and contamination factor C_f^i . The Tr^i of the heavy metals were as follows: Mercury= 40, Arsenic= 10 and Cadmium= 30. The results were interpreted using the geoaccumulation index, E_r^i and PERI classification of Hakanson (1980) as seen in Table 1.

Table 1: Classification of ecological risk based on geoaccumulation index, potential ecological risk factor and index

Igeo value	Risk classification	E_r^i value	Risk classification	PERI value	Risk classification
$I_{geo} \leq 0$	Practically unpolluted	<40	Low risk	≤ 150	Low risk
$0 \leq I_{geo} \leq 1$	Unpolluted to moderately	40–80	Moderate risk	$150 < PER \leq 300$	Moderate risk
$1 \leq I_{geo} \leq 2$	Moderately polluted	80–160	Considerable Risk	$300 < PER \leq 600$	Considerable risk
$2 \leq I_{geo} \leq 3$	Moderately to strongly polluted	160–320	High risk	$PER > 600$	High risk
$3 \leq I_{geo} \leq 4$	Strongly polluted	≥ 320	Very high Risk		
$4 \leq I_{geo} \leq 5$	Strongly to extremely polluted				
$I_{geo} > 5$	Extremely polluted				

* E_r^i and PERI classification of Hakanson (1980)

Human Risk Assessment

Non-Carcinogenic Risk Assessment

The noncarcinogenic risk of heavy metals in soil was established by computing for hazard quotient (HQ) and hazard index (HI). HQ was computed using this equation (Chonokhuu *et al.*, 2019):

$HQ = \text{average daily dose or ADD/RfD or reference dose of heavy metals in mg/kg/day}$

where average daily dose (ADD) referred to the daily dose of heavy metal exposure in contaminated soil while reference dose of heavy metals in mg/kg/day (RfD) referred to estimate of persistent heavy metal exposure by the affected residents. The RfD of arsenic was based on Ma *et al.* (2019) and the RfD per pathway were as follows: ingestion = 3.00×10^{-4} , inhalation = 5.00×10^{-5} and dermal = 3.00×10^{-4} . If the hazard quotient < 1 , there was no potential health effects but if the value was > 1 , there was potential health effects from exposure to contaminated soil.

Aside from hazard quotient, hazard index (HI) was also computed to determine the total noncarcinogenic risk for each metal. It was computed by adding the hazard quotient for each metal and the study used this equation:

$$HI_{\text{metal}} = HQ_{\text{ing}} + HQ_{\text{dermal}} + HQ_{\text{inh}}$$

The hazard quotients for each metal were added and were interpreted as follows: An HI value equal to or less than 1 signified the absence of non-carcinogenic risk from heavy metal exposure in contaminated soil but an HI value of more than 1 indicated that there was a potential noncarcinogenic risks from an exposure to contaminated soil.

Carcinogenic Risk Assessment of the Soil

Carcinogenic risk from heavy metal exposure in the soil was also determined and it was computed using this equation (Ma *et al.*, 2019):

$$CR = ADD \times SF$$

where CR referred to the carcinogenic risk from an exposure to a specific metal while SF was the cancer slope factor of a specific metal. The SF of arsenic based on pathway (Ma *et al.* 2019) were the following: ingestion = 1.5, inhalation = 15.1 and dermal = 3.66. It was interpreted as follows: (a) CR less than 1×10^{-6} was interpreted as having no carcinogenic risk; (b) a CR value of more than 1×10^{-6} but less than 1×10^{-4} or $1 \times 10^{-6} < CR < 1 \times 10^{-4}$ signified that the metal exposure in the soil was within acceptable levels and had lesser chances of carcinogenic risk; and (c) $CR > 1 \times 10^{-4}$ indicated that there was significant potential of carcinogenic risk from an exposure in contaminated soil. It was computed using Microsoft excel.

RESULTS AND DISCUSSION

Heavy Metal Concentration in the Soil

The arsenic concentration in the soil of Talisay, Batangas and Tagaytay, Cavite have two- to three-fold increase and one- to two-fold elevation than the reference value, respectively, while the arsenic in the soil of Cuenca,

Batangas is maintained within the reference value (Table 2). Meanwhile, cadmium and mercury concentration in the soil of the three municipalities remains within the reference value.

Martinez-Villegas *et al.* (2022) reported that volcanic contents were carried by the wind towards the northeast side of Taal volcano, where Talisay, Batangas is situated, during the 2020 volcano eruption. However, the direction of the wind redirected towards the southwest side of the volcano and it blew lesser ash content than the actual volcanic eruption. The volcanic contents are known to be comprised of elements and even heavy metals that can be harmful to those who will be exposed (Jenkins *et al.*, 2015). Since volcanic contents is blown towards the northeastern side of the volcano during the actual eruption, most of the ashes might have settled on the ground of Talisay, Batangas. Meanwhile, Tagaytay City, Cavite is the municipality that is located beside Talisay, Batangas and it has also been exposed during the eruption. Given this information, these municipalities had been greatly exposed during the volcanic eruption but it is Talisay, Batangas which is likely to have obtained more ashes than Tagaytay City, Cavite.

Aside from the direction of the wind, earthquakes were also observed during the eruption and such event may have disturbed the other soil contents. Broken glasswares were observed in some of the collection sites in Talisay, Batangas. Between Talisay and Tagaytay, Talisay has a significantly high arsenic concentration, and these glasswares may have also contributed to the soil contamination. The heat from the environment may react with the glasswares which will trigger the release of arsenic. This concept may also explain the arsenic in the soil of the municipality. Aside from the actual observation of the soil, the groundwater of Talisay, Batangas was discovered to be contaminated by arsenic in the study of Apostol *et al.* (2022). They discussed that it is possible that these water from wells have access to the volcanic contents. This contaminated groundwater may also have contributed in the arsenic contamination in the soil of Talisay, Batangas as it flows through the land. The direction of the wind, the shaking of the ground during earthquakes and groundwater contamination are the possible sources of the elevated arsenic in the soil of the two municipalities especially Talisay, Batangas.

Anthropogenic sources is also a source of metal contamination and may have contributed in the elevated arsenic concentration in the soil of the two municipalities. Fertilizers have been applied in some of the soil collection sites of Talisay, Batangas. Wuana and Okieiman (2011) mentioned that fertilizers and pesticides are made-up of arsenic and such chemicals may take several months before it is eliminated from the land. In the same study, they also discussed that burning of fuels may produce dust particles that contains arsenic. In relation to the study, the soil in some of the collection sites in Talisay, Batangas have been treated with fertilizers. Moreover, the soil collection sites in Talisay, Batangas and

Tagaytay, Cavite is located at least 50 meters away from the roadside. These factors may have also enhanced the arsenic concentration in the soil of the two municipalities aside from the natural sources.

Table 2: Comparison of detected heavy metal concentration in the soil of different municipalities to and its reference values

Municipality	Arsenic		Cadmium		Mercury	
	Mean (ppm)	Reference value (ppm)	Mean (ppm)	Reference value (ppm)	Mean (ppm)	Reference value (ppm)
Talisay, Batangas	5.26	2.0 (DENR)	<0.03	0.075 (USEPA)	<0.08	1.8 (US EPA)
Tagaytay, Cavite	3.94		<0.03		<0.08	
Cuenca, Batangas	1.92		<0.03		<0.08	

Ecological Risk Assessment

The soil samples of Tagaytay, Cavite (Igeo=0.40) and Talisay, Batangas (Igeo=0.81) were classified as unpolluted to moderately polluted while Cuenca, Batangas has practically unpolluted soil (Igeo=-0.64). In terms of enrichment factor, the soil of Cuenca, Batangas and Tagaytay City, Cavite were classified as having deficient to

minimal enrichment because its enrichment factor is 0.96 and 1.98, respectively, which are less than <2 (reference value). Despite having the minimal differences in other aspects of ecological risk assessment, the soil from all three municipalities has low ecological risk for having arsenic in its soil (Table 3).

Table 3: Comparison of the ecological risk assessment of arsenic-contaminated soil of the affected municipalities of Taal volcano eruption

	Cuenca	Tagaytay	Talisay
Igeo	-0.64	0.40	0.81
Interpretation of Igeo	Practically unpolluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Enrichment factor (EF)	0.96	1.98	2.63
Interpretation of EF	Deficiency to minimal enrichment	Deficiency to minimal enrichment	Moderate enrichment
Potential ecological risk of arsenic (Er)	9.6	19.75	26.3
Interpretation of Er	Low risk	Low risk	Low risk

The metals that were recognized to have moderately to strongly polluted the environment were cadmium, chromium, mercury, lead and arsenic, with their maximum Igeo ranging between 2.7 to 6.2 (Radomirovic *et al.*, 2020). In contrary, Chen *et al.* (2021) discovered that arsenic concentration from different lands with plant species regardless of abundance and from a soil that is located in residential area demonstrated a non-polluted soil. Moreover, a strong to severe ecological risks is observed in a land with significant vehicular exposure and land manipulation. Like the result of Chen *et al.* (2021), the finding of this study also has a low ecological risk in arsenic-contaminated soil. In this study, the soil samples were collected from a land that is located from either of the following: with minimal vehicular exposure and/or directly from the backyard of a residential house. Moreover, no industrial companies were located nearby or surrounding the collection sites. The study of Radomirovic *et al.* (2020) showed an increased enrichment factor (2.4 to 12) when compared to the reference value of less than 2 and their soil were collected from an area with industrial leakage. Meanwhile, Ahmad *et al.* (2021) also detected a moderately heavy metal-contaminated and -polluted soil from a landfill. This signifies that the

possibility of heavy metal contamination and pollution in the soil will depend on the location of soil collection and the amount of exposure to chemicals or discharges from industrial companies. In relation to the study, the soil collection site of Cuenca is close to Taal Lake and it would require 1,500 steps before reaching the roadside. Due to the absence of exposure to anthropogenic activities, the enrichment factor in Cuenca, Batangas and Tagaytay City, Cavite demonstrate that the arsenic can be from the earth's crust. Meanwhile, the moderate enrichment in Talisay, Batangas was due to the natural and anthropogenic sources that have been identified. The identified anthropogenic sources of arsenic in the soil of Talisay, Batangas were fertilizers, glassware and smoke from vehicles. This study showed that there is still low ecological risk despite an arsenic concentration of up to three-fold elevation in the soil. This demonstrates that such concentration is not yet harmful to the environment.

Human Health Risk Assessment

Non-carcinogenic risks from an exposure to the soil of the three municipalities demonstrated a hazard quotient and hazard index values of <1 and they signified that an exposure to arsenic-contaminated soil do not pose

a potential health effect and risk to both adult and children regardless of point of entry in the body (Table 4). Moreover, there is still no possibility for residents to

develop cancer from an exposure to arsenic-contaminated soil based on the carcinogenic value of less than 1 from the soil of Cuenca, Tagaytay and Talisay.

Table 4: Non-carcinogenic and carcinogenic risk assessments from a possible exposure to arsenic-contaminated soil after the Taal volcano eruption

Non-Carcinogenic Risk				
	Age group	Cuenca	Tagaytay	Talisay
Hazard index (HI)	Adult	1.7×10^{-4}	3.3×10^{-4}	4.5×10^{-4}
	Children	1.0×10^{-4}	2.1×10^{-4}	2.8×10^{-4}
	Interpretation	Absence of non-carcinogenic risks		
Carcinogenic Risk				
	Adult	1.2×10^{-9}	2.4×10^{-9}	3.2×10^{-9}
	Children	3.5×10^{-8}	7.2×10^{-8}	9.6×10^{-8}
	Interpretation	No chances of carcinogenic risks		

Health risk from an exposure to arsenic is most likely to occur through ingestion and less of the other pathways. However, it is through ingestion of arsenic-contaminated water that both non-carcinogenic and carcinogenic health risks are identified and most likely to be observed. Children are more exposed than adults especially when they are in an area near a roadside and/or industrial companies and oral route is considered as the common pathway of their exposure (Riaz *et al.*, 2022).

Arsenic exposure cannot cause an immediate effect in the health of a living organism, instead, it would require a prolonged exposure to it (Lou *et al.*, 2010). In the study of Apostol *et al.* (2022), the groundwater was discovered to be contaminated with arsenic. Given this information, the groundwater can be one of the means of human exposure. In terms of arsenic-contaminated soil, the only way for humans to ingest arsenic is through the crops that grew in it. The current arsenic concentration in the soil of Tagaytay City, Cavite and Talisay, Batangas will not yet pose noncarcinogenic and carcinogenic risks which means that it is still not harmful to the exposed residents.

CONCLUSION

The study discovered that the soil from Cuenca, Talisay and Tagaytay were unpolluted to moderately polluted, have low to moderate contamination and have low potential ecological risk from arsenic. The location of the soil collection contributed to this result. There is lesser possibility for the soil to cause a potential ecological risk, to be polluted and contaminated by arsenic when the soil is taken from an area that is devoid and distant from anthropogenic sources. The soil samples of Talisay had other environmental factors such as fertilizers, broken glasswares and minimal exposure to vehicular smoke that led to moderate enrichment of the soil. Thus, a combination of environmental exposure to chemicals and actual soil collection sites affect the enrichment factor of an area. The soil may not directly cause a non-carcinogenic and carcinogenic risks to a person but we cannot totally eliminate the possibility of arsenic exposure through

ingestion of the crops. The current arsenic concentration in the soil of Talisay, Batangas and Tagaytay City, Cavite will not yet cause any significant harm to the environment and to the exposed residents.

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