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Radionuclide Consumption Health Risk Assessment of Asian Clam (*Corbicula fluminea*) in Volcanic Lake of Taal, Philippines

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ABSTRACT

The recent eruptions of the Taal volcano in the Philippines have produced more andesitic rocks than prior historic eruptions. Increased rock acidity is associated with higher concentrations of radionuclides. Local food source filter feeders like the Asian clam (Corbicula fluminea), feed on organic matter through filtration resulting in higher risks of taking in pollutants. The study aimed to assess the health risks through various metrics of radiologic health assessment via food ingestion. Three known harvesting sites were selected around the volcano island in the lake (S: Saluyan, C: Calawit, BM: Binintiang Munti). Two clam morphs: white morph (W) and purple morph (P) were analyzed for naturally occurring radioactive materials using High-purity Germanium gamma-ray spectrometer. Health assessments were analyzed using Committed Effective Dose (CED) and Lifetime Cancer Risk (LCR) equivalent for a person who consumes one heavy clam meal a week (17.86 g day^{-1}). Overall, CEDs are valued far below the recommended 3×10^{-1} mSv yr^{-1}, and LCRs are below the recommended 1×10^{-4} values. It can be concluded that regular consumption of Asian clams in Taal Lake carries no imminent risks in terms of radionuclide ingestion as long as no more acidic eruptions would follow.

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INTRODUCTION

The Taal Volcano in the Philippines has a recorded history of 38 Holocene eruptions. A major eruption happened in January 2020 and several minor eruptions in the two succeeding years (*Venzke 2022, PHIVOLCS 2022*). The nature of these eruptions is mostly phreatomagmatic and at times phreatic with a major component of andesitic rocks as part of their volcanic products (*Balangue-Tarriela et al. 2022*). It is widely acknowledged that intermediate to acidic rocks, such as andesites and rhyolites, exhibit a significantly higher concentration of naturally occurring radioactive materials (NORMs) (**Table 1**). This phenomenon has been substantiated by numerous studies (*Cinelli et al. 2019, Lanzo et al. 2010, Taboada et al. 2006).* Considering the more acidic composition of the magma in comparison to previous eruptions, it is imperative to undertake environmental monitoring to assess the potential uptake of radionuclides by humans through foodstuff. This is of utmost importance due to the fact that the surrounding lake serves as a vital source of sustenance for the local population and is occasionally even utilized for exportation to other locations beyond the province of Batangas.

Freshwater clams, collectively known locally as 'tulya' and 'peras' are staple molluscan catch in the lakes of Taal and Laguna for human consumption (*Mutia et al. 2017, Papa and Mamaril 2011, Diwa et al. 2022*). Filter feeders , such as the Asian clam (*Corbicula fluminea*) that is abundant in Taal Lake, filters

Table 1. Natural abundance of radionuclides by rock type (*Cinelli et al. 2019*).

Rock Type	Uranium	Thorium	Potassium
Acidic	2-50 mg kg^{-1}	10-50 mg kg^{-1}	2.5-6 mg kg^{-1}
Intermediate	1-6 mg kg^{-1}	>10 mg kg^{-1}	1-2 mg kg^{-1}
Basic	< 1 mg kg^{-1}	0.1- 4 mg kg^{-1}	0.5-1.3 mg kg^{-1}

organic matter making them more prone to higher concentrations of pollutants and potential food contaminants (*Tan et al. 2023, Almazan-Torres 2025*). With this feeding behavior, they are used as bioindicators for the overall health and safety of marine and freshwater ecosystems (*Boening 1999*). This threat to the safety and mortality of foodstuff is very much considered as a public health concern. The Asian clam (*C. fluminea*) has a lifespan of about 1-7 years (*USGS 2023, Sousa et al. 2008*). This makes the current stock still within a generation of potentially contaminated samples from the heavy ashfall since 2020.

Amongst the site surveys, environmental radioactive ingestion is often overlooked as a potential health assessment tool. This study thus aims to assess the state at which aquatic fauna, specifically the Asian clam, uptakes radionuclides in their system that human consumers could potentially ingest.. The radionuclides in question would be ^{238}U, ^{232}Th, and ^{40}K. The study also aims to assess the human health risks from consuming this species through various metrics, specifically calculating the committed effective dose and lifetime cancer risk.

MATERIALS AND METHODS

Sampling Location and Procedure

The study was conducted in Taal Lake, Philippines with sampling locations in San Nicolas, Batangas; areas near Binintiang Munti, Saluyan; and Balete, Batangas, on the coast of Calawit. These sites have a reported history of harvest and consumption according to the fisherfolk (**Figure 1**). Specimens of the clam species were gathered by the fisherfolk via traditional methods of harvesting. Hand grabbing is the simplest of the methods, with straightforward procedures. Clams were picked randomly and were limited to living samples, reflecting typical consumption of fresh catch clams. The sampling size of each sampling site was determined to be 5 kg in total cumulative wet weight, regardless of the age of the clams. Before processing, 30 clams from each sampling location were randomly measured morphometrically using a vernier caliper for characterization. Afterward, the Niku-nuki method was performed to separate the soft flesh and the hard shell among the samples (*Fukuda et al. 2008*). The Niku-nuki method quickly dispatches an organism and preserves its flesh by immersing it in boiling water for a very short time, avoiding cooking. The flesh samples were then air-dried for approximately 240 h. followed by a 24-hour oven drying session at 55^{o}C controlled temperature. The samples were then reweighed for dry-weighing and then pulverized. Pulverization was done using an agate mortar and pestle to avoid

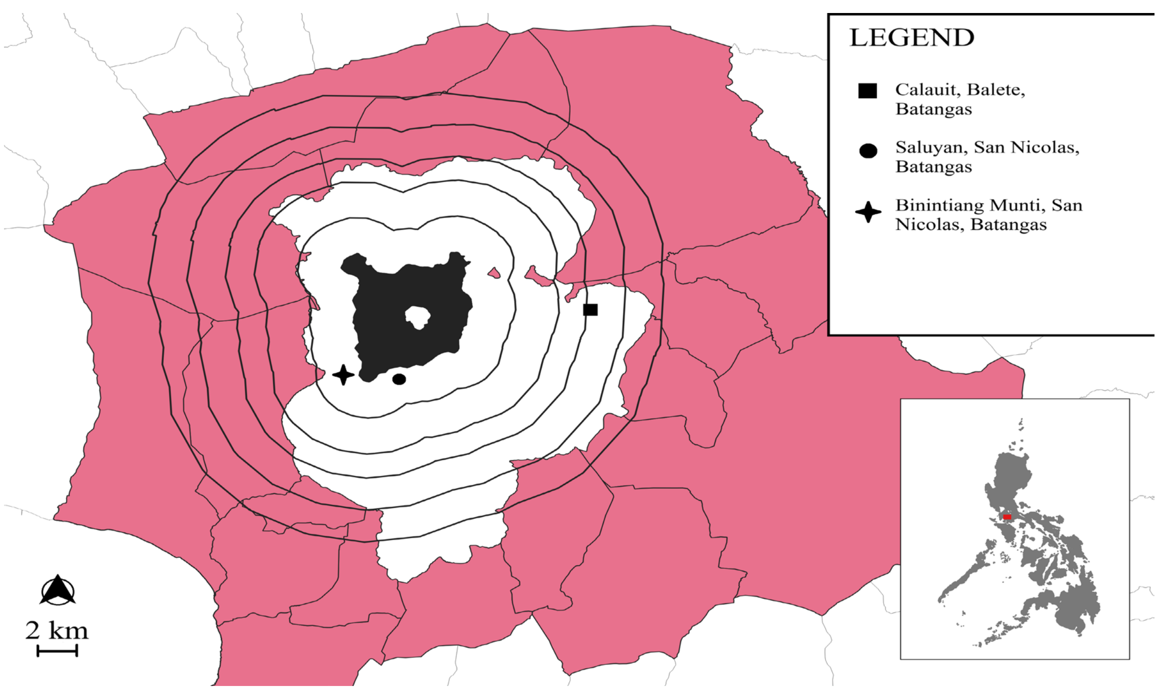

Figure 1. Location of sampling sites. Map of the Taal Lake, Batangas, Philippines with lines representing 2-km distance intervals away from the main volcano island, laid out using ArcGis. Pink areas pertain to the Batangas provincial boundaries of the lake.

metallic contamination. The pulverized samples underwent secular equilibrium and were analyzed using a p-Type Ortec GEM25-p4-76rb High Purity Germanium detector linked to an Ortec Digital Interface Module Positive Ge and Ortec DISPEC jr. 2.0 Digital Gamma-ray Spectrometer, following the procedure for radionuclide analysis of solid samples in the Nuclear Analytical Laboratory of the Philippine Nuclear Research Institute.

Activity Concentration of Samples

The activity concentration *A* of the sample in Becquerel per kilogram (Bq kg^{-1}) can be calculated (Equation 1) (*Khot et al. 2018, Khandaker et al. 2013*):

$$A_i = \frac{\frac{N}{T_{count,N}} - \frac{B}{T_{count,B}}}{P_{\gamma i} \cdot \varepsilon_i \cdot W_{dry}} \tag{1}$$

Where *N* is the net count of the sample; *B* is the background count of the ambient from an empty 250 mL Nalgene bottle; the counting time of the sample ($T_{count,\ N}$), and the background ($T_{count,\ B}$), from an empty Nalgene bottle; ε_i is the efficiency of i-th radionuclide gamma energy; P_{yi} is the emission probability of i-th radionuclide; and *W dry* for the sample's dried weight. For a sample with its original (wet) weight, the activity could be expressed (Equation 2):

$$A_{wet,i} = CF \cdot A_i \tag{2}$$

Where *CF* refers to the conversion factor expressed as the ratio of dry weight to wet weight ($W_{dry}\ W_{wet}^{-1}$).

Minimum Detectable Activity

The minimum detectable activity (MDA) is a measure that ensures the least amount of activity that can be confidently measured on a system, usually defined under α= 0.05 cases. The formula (Equation 3), as provided by the International Atomic Energy Agency (IAEA) and the US Environmental Protection Agency (USEPA) (*Hwang et al. 1992, Gilmore 2008*), is:

$$MDA = \frac{4.65\sigma + 2.71}{kT} \tag{3}$$

Where σ refers to the standard deviation (for 95% confidence level, $\sigma = \sqrt{B}$); *k* refers to product efficiency and other factors of conversion ($\varepsilon \cdot P_\gamma \cdot W_{dry}$) (*Khot et al. 2018*); and *T* for counting time in minutes. This is related to the limit of detection (LD) (Equation 4):

$$L_D = 4.65\sigma + 2.71 \tag{4}$$

Committed Effective Dose

Since these clams are ingested, each species should also be assessed by its committed effective dose (CED). This would factor in the consumer's ingestion rate, catch rate, and edible fraction to holistically assess the dosage per consumer. The CED is expressed under this formula (*Makmur et al. 2020*) (Equation 5):

$$CED = \sum_i A_{wet,i} \cdot I_R \cdot D_{Fi} \cdot M_i \cdot E \cdot F \tag{5}$$

Whereas, *i* is the radionuclide in question; A_i is the activity by i-th radionuclide in Bq kg^{-1}; I_R is the average daily consumption set as one meal a week (125 g per week, 17.86 g per day); D_{FI} is the dose conversion factor per unit intake of i-th radionuclide in microSievert per Becquerel (μSv Bq^{-1}) (using values of 2.8×10^{-7} μSv Bq^{-1} for ^{226}Ra; 2.3×10^{-7} μSv Bq^{-1} for ^{232}Th; 6.2×10^{-9} μSv Bq^{-1} for ^{40}K) (*ICRP 1996*); M_i is the modifying factor, this is essentially the time measured between catch and the ingestion or consumption per i-th radionuclide, here this is set to 1 (assumption of immediate consumption); *E* is the exposure frequency (expressed as 365 days per year); and the *F* is the real fraction consumed. For clams, it is estimated to be 1 since this is analyzed purely from flesh samples.

Lifetime Cancer Risk

The probability of carcinogenic risk from radionuclide consumption can be calculated using this factor modified from USEPA by other similar studies (*USEPA 1999, Khandaker et al. 2015*) (Equation 6):

$$LCR = \sum_i AA_i \cdot ED \cdot RC_i \tag{6}$$

RESULTS AND DISCUSSION

Characterization and Status of Samples

The clams have been observed to have two morphologies. This observation was also documented in other studies concerning the Asian clam (*Wang et al. 2014, Park et al. 2002*). The samples consist of both morphs: the white morph (W) (**Figure 2a**) and the purple morph (P) (**Figure 2b**). The white morph showed a greenish outer shell coloration with a light green valve on its ventral side. The shell inside is creamy white, hence the name assigned in this study. The purple morph, on the other hand, has a generally dark brown to blackish shell exterior. The shell when opened is purple, hence the name givenin this study. Both samples visually exhibit the same general anatomical features, like umbo size, height-

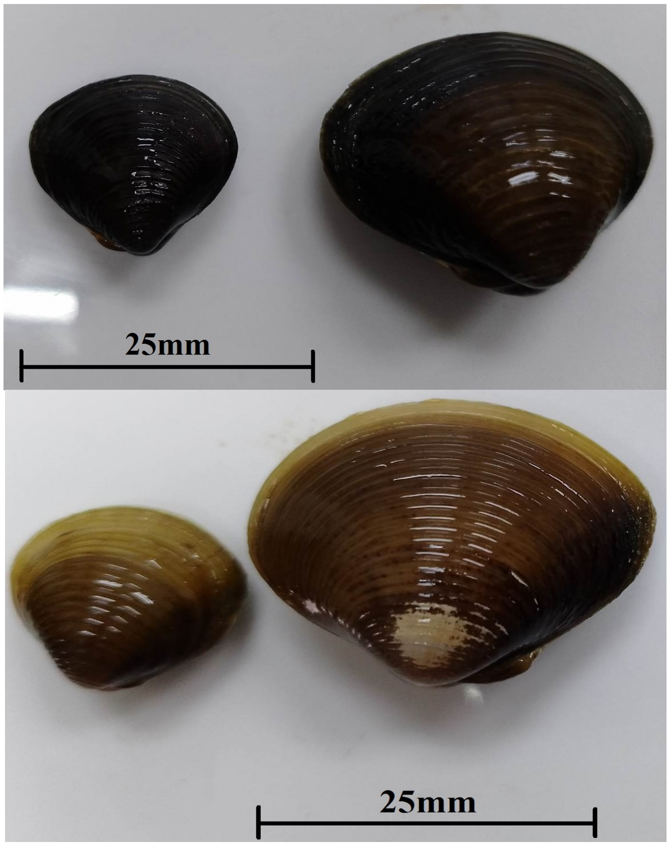

Figure 2. Species morphologies: TOP: Purple morph (P), with a blackish shell exterior and purple shell interior; BOTTOM: White morph (W), with greenish shell exterior and creamy white shell interior.

to-length ratio, and overall proportion. The samples in Saluyan averaged in length at about 22.49 mm for the white morph and 20.05 mm for the purple morph. The second site was around Calawit, Balete. The initial harvest weight was 5.19 kg. The samples on this site exhibited the largest average length for both morphs of the species (23.67 mm and 21.13 mm for the white morph and the purple morph, respectively). For Binintiang Munti, San Nicolas, the harvest weight was 5 kg, and it exhibited the smallest average length among the sites (21.03 mm and 19 mm for the white morph and the purple morph, respectively) (**Table 2**).

Radionuclide Analysis

The gamma spectrometer itself cannot directly cite values of the parent radionuclides reliably. Results shown are of its daughter radionuclides, which emit a gamma emission that does not interfere with signals from other radionuclides in the gamma spectrometer. The following detected radionuclides are as follows: for the ^{238}U series, this study have the ^{214}Pb and ^{214}Bi, with a usable gamma energy of 351.93 keV and 1,764.49 keV respectively. For the ^{232}Th series, we have the ^{208}Tl and ^{228}Ac, with a usable gamma energy of 583.19 keV and 911.20 keV, respectively (*Gilmore 2008*).

Studies about the bioaccumulation of uranium in clams show that clams can intake about 16% through direct exposure via water (*Simon and Garnier-Laplace 2004*). Most radionuclides detected are below the minimum detectable activity (**Table 3**). Additionally, it is worth noting that very high radioactive volcanic products in the first place was not expected, but sources could potentially come from the volcanic product itself or other anthropogenic and natural sources (**Table 1**). Regardless, the results still validated that the recorded concentrations in a representative foodstuff are low.

The values of the CED are observed to be highest for the Binintiang Munti's white morph clams and lowest for the Calawit's white morph (**Table 4**). The same observation can be seen in the LCR values for both male and female consumers. Interestingly, Calawit is also the farthest from the volcanic island.

By inspection, white morph samples have a tendency to exhibit higher bioaccumulation levels than the purple morph clams in locations near the volcanic island (i.e., Saluyan and Binintiang Munti), but the opposite is true for the ones collected in Calawit. The computed data from these morphologies on this study, therefore, generally do not follow a trend that can be deduced about whether one is a better bioaccumulation than the other.

Research pertaining to the presence of ingested

Table 2. Clam harvest characterizations from three locations in Taal Lake, Philippines, 2023.

Location	Morph	Moisture Content (WC) (%)	Conversion Factor (CF)	Average Length (mm)
Saluyan	W	86.63	0.1337	22.49
	P	88.69	0.1131	20.05
Calawit	W	87.63	0.1237	23.67
	P	87.74	0.1226	21.13
Binitiang	W	88.19	0.1181	21.03
Munti	P	86.73	0.1327	19.00

Note: W (White Morph); P (Purple Morph)

Table 3. Beta decay (β), electron capture (EC), emission probability, efficiency, and activity concentration (AC) of Asian clam (*Corbicula fluminea*) samples from Taal Lake in Barangays Saluyan, Calawit, Binintiang Munti in Taal, Batangas, Philippines. MDA refers to Minimum Detectable Activity. It is noticeable that most radionuclides are below the MDA.

Gamma Ray Analysis		Parent	Daughter	Decay	P_γ	ε	AC(Bq kg^{-1})
Location	Morph						
Saluyan	W	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	<MDA
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	9
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	<MDA
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	61
	P	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	<MDA
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	12
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	<MDA
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	<MDA
Calawit	W	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	<MDA
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	6
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	<MDA
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	51
	P	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	<MDA
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	11
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	<MDA
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	<MDA
Binitiang Munti	W	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	2
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	9
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	10
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	64
	P	U-238	Pb-214	$\beta-$ (100%)	35.6	0.045659	<MDA
			Bi-214	$\beta-$ (99.98%)	45.49	0.009952	16
		Th-232	Tl-208	$\beta-$ (100%)	85	0.010973	<MDA
			Ac-228	$\beta-$ (100%)	25.8	0.005257	<MDA
		K-40	K-40	$\beta-$ (89.28%),EC	10.66	0.004796	66

Note: W (White Morph); P (Purple Morph)

Table 4. Radionuclide health risk assessment of Asian clam (*Corbicula fluminea*) samples from Taal Lake in Barangays Saluyan, Calawit, Binintiang Munti in Taal, Batangas, Philippines using committed effective dose (CED) and lifetime cancer risk (LCR) calculations.

Location	Morph	CED (mSv y^{-1})	LCR (Males)	LCR (Females)
Saluyan	W	2.526×10^{-3}	7.170×10^{-6}	7.919×10^{-6}
	P	2.684×10^{-3}	6.198×10^{-6}	6.846×10^{-6}
Calawit	W	1.610×10^{-3}	4.751×10^{-6}	5.247×10^{-6}
	P	2.461×10^{-3}	5.682×10^{-6}	6.276×10^{-6}
Binitiang Munti	W	4.415×10^{-3}	2.350×10^{-5}	2.595×10^{-5}
	P	4.228×10	1.120×10^{-5}	1.237×10^{-5}

Note: W (White Morph); P (Purple Morph)

radioactive materials in Taal lake and its surrounding areas is notably scarce. Organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the United States Environmental Protection Agency (USEPA) have delineated their recommended thresholds for safe deterministic levels, wherein the potential risks associated with radionuclide exposure and ingestion are deemed minimal and inconsequential (**Table 5**).

Values of CED for radionuclides are insignificant with an effective dose of around 1.6 to 4.4 μSv yr^{-1}, this is

Table 5. Comparison of recommended limits and this study (*UNSCEAR 2000, USEPA 1999*).

Study	Range	CED (mSv y^{-1})	LCR (Males)	LCR (Females)	Comments
This study	Min	1.610×10^{-3}	4.751×10^{-6}	5.247×10^{-6}	
	Max	4.415×10^{-3}	2.350×10^{-5}		
UNSCEAR		3.00×10^{-1}	-	-	Recommended limit
USEPA		-	1.00×10^{-4}	1.00×10^{-4}	

Note: (CED) committed effective dose; (LCR) lifetime cancer risk

far below the recommended threshold by the UNSCEAR. An equivalent dose of this magnitude is also comparably far below the recommended public exposure dose limit for radiation of 1 mSv y^{-1} (*IAEA 2014*). For context, this level of effective dose is about a thousandth of that of an average lumbar spine diagnostic x-ray radiography procedure to about a diagnostic computed tomography imaging for the abdomen (*Mettler Jr et al. 2008*).

This preliminary observation provides initial evidence that the bioaccumulation of uranium and thorium is at a sufficiently low level. While the concentration derived from a bioaccumulator alone may not provide a comprehensive assessment of the overall concentration of these radionuclides in the environment, it does serve as an indication that the bioaccumulation of such radionuclides is low in the soil and water environments where the clams primarily inhabit. It is worth noting that other studies on mollusks have also reported similar findings in relation to this observation (i.e., relatively small bioaccumulation correlates to relatively small soil and water radionuclide concentration) (*Ryan et al. 2005, Jia et al. 2020*).

CONCLUSION AND RECOMMENDATION

Generally, for a lifetime continuous consumption, the interpretation for the cancer risk is having a roughly 4.751 to 25.95 out of 100,000 probability of contracting one. These values are marginally lower than the recommended threshold for radiological risk at 10^{-4}. Since most values are at low 10^{-5} and 10^{-6}, these are borderline insignificant (*Pereira et al. 2021*). Furthermore, it is plausible to consider that even if the volcanic products yield a more acidic composition of rocks, the level of inherent radioactivity remains negligibly lower than the prescribed deterministic thresholds.

It is important to note that the figures presented assume a heavy weekly consumption level (125 g of wet clam flesh weight per week). More frequent consumption would therefore lead to proportionally higher values. However, even if consumption doubles or triples, it is likely to remain well below recommended safety limits. Therefore, in terms of radionuclide health risks, and also biologically attributed to the low trophic level of the clams and the filter-feeding nature of the clams, the consumption of the majority of the foodstuff in the lake of Taal is safe. This statement has a likelihood to stay true as long as no new more acidic eruption would follow, as the ultimate source of radionuclide contamination is still predominantly assumed to be attributed to natural causes, and other potential major anthropogenic causes are absent within the vicinity (i.e., nuclear power plants, mining operations, etc.) (*Hu et al. 2010*). It is recommended to also test for alpha-emitting radionuclides (more specifically ^{210}Po), albeit as tested here, the parent series (^{238}U from 2^{14}Pb and ^{214}Bi) showed little readings, bivalves and aquatic organisms are found to be more sensitive to the highly toxic polonium, hence, many other study tests directly for polonium (*Duong et al. 2023, Makmur et al. 2020*).

Concerns about food safety now include both biological and chemical risks, particularly those associated with radionuclides and heavy metals introduced by volcanic eruptions (*Ma et al. 2019*). In nearby areas of Taal, high levels of arsenic have been detected in soil (*Banta and Salibay 2023*). While a study on the endemic freshwater sardine (*Sardinella tawilis*) examined mercury, lead, and cadmium (*Serrano et al. 2023*), arsenic was not included. Future research should address both radiological and chemical hazards to better assess food safety and human health risks.

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