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Assessment of Health Risks from Cadmium and Lead Contamination in Aquatic Animals near the Kwai Noi River

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Abstract

This study assesses the health risks associated with cadmium and lead contamination in aquatic animals consumed by local populations near the Kwai Noi River in Makham Sung Subdistrict, Phitsanulok, Thailand. Four commonly consumed species—freshwater shrimp, pond snails, silver barb, and Nile tilapia—were analyzed for cadmium and lead levels. The results show that freshwater shrimp and pond snails contained the highest levels of contamination, although these levels were within Thai food safety standards for cadmium (0.20 mg/kg) and lead (1 mg/kg). Health risks were evaluated using Chronic Daily Intake (CDI) and Hazard Quotients (HQ), revealing no significant immediate risk to consumers, as HQ values remained below 1. Lead intake, though classified as carcinogenic, was found to be significantly below the tolerable daily intake. Community participation played a key role in knowledge dissemination and risk management, with the study emphasizing the need for ongoing monitoring and public education to mitigate long-term bioaccumulation risks.

Keywords: Cadmium, Lead, Aquatic animals, Health risk assessment

1. Introduction

Contamination of food sources by heavy metals, particularly cadmium and lead, is an escalating environmental and public health issue worldwide. These toxic metals are persistent in the environment and can bioaccumulate in food chains, leading to severe health risks for humans and animals. Both cadmium and lead are classified as non-essential elements for biological systems and pose significant risks even at low concentrations (Järup, 2003). Chronic exposure to cadmium has been associated with renal dysfunction, osteoporosis, and various cancers, while lead exposure can cause neurotoxicity, cognitive impairments, and cardiovascular issues (Godt et al., 2006; Lanphear et al., 2005).

Cadmium (Cd) and lead (Pb) contamination has been reported in various regions worldwide, posing significant health risks due to their toxicity and bioaccumulation in food chains. Studies have shown that prolonged exposure to these heavy metals can lead to severe health effects, including kidney damage, neurological disorders, and developmental impairments in children (Massányi et al., 2020; Satarug et al., 2020). For example, research conducted in industrial areas of China and India has revealed elevated levels of Cd and Pb in locally consumed aquatic species, raising concerns about human health risks (Burger et al., 2014; Santhosh et al., 2024). These findings highlight the necessity of monitoring heavy metal contamination in agricultural and aquatic environments to assess potential exposure risks.

In rural communities, especially in developing countries, the risk of heavy metal exposure through contaminated aquatic animals is of particular concern. Local populations that depend heavily on rivers for food, agriculture, and livelihood are at a heightened risk. Aquatic animals, such as fish, shrimp, and snails, can bioaccumulate heavy metals from contaminated water and sediment. Through the process of biomagnification, these toxins become concentrated in organisms at higher trophic levels, making them more hazardous to humans (Burger et al., 2014; Rouzbahani, 2017).

Thailand, with its vast network of rivers and dependence on freshwater ecosystems, faces significant challenges regarding environmental contamination. The Kwai Noi River, a major freshwater source for the

Makham Sung Subdistrict in Phitsanulok Province, supports the local population's agricultural practices and daily consumption of aquatic animals. Studies have shown that cadmium and lead contamination in aquatic ecosystems can stem from various sources, including agricultural runoff, industrial waste, and improper disposal of hazardous materials (Nguyen et al., 2005). Given the reliance of local communities on these freshwater sources, the potential for human exposure to heavy metals through the consumption of aquatic organisms is substantial.

This study aims to assess the concentrations of cadmium and lead in four commonly consumed aquatic animals—freshwater shrimp, pond snails, silver barb, and Nile tilapia—collected from the Kwai Noi River. Additionally, the study evaluates the health risks posed to local communities by analyzing metal concentrations against established safety thresholds. By understanding the level of contamination and associated health risks, the study also proposes practical strategies for community-based interventions and knowledge management to mitigate these risks.

2. Methodology

The study area is located in Makham Sung Subdistrict, Phitsanulok, Thailand, which is characterized as agricultural area. The area was selected due to its potential exposure to heavy metals from agricultural chemical usage (Rashid et al., 2023; Wang et al., 2024). The geographical and environmental conditions of the study area are depicted in Figure 1.

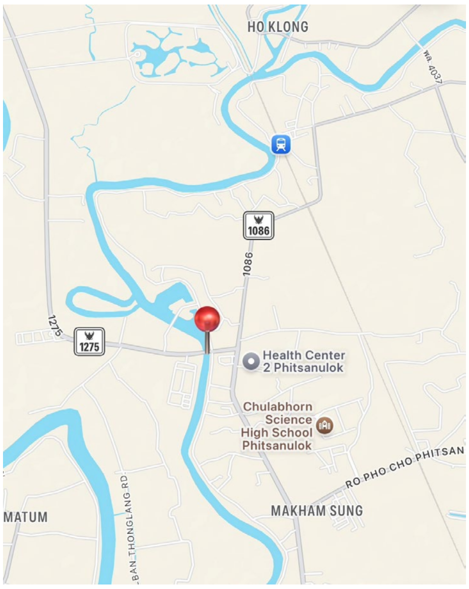

Figure 1. The study area in Makham Sung Subdistrict, Phitsanulok, Thailand

2.1 Sampling of aquatic animals

Four species of aquatic animals commonly consumed by the local population were selected for analysis:

1. Freshwater shrimp (**Macrobrachium* spp.*)
2. Pond snail (**Filopaludina* spp.*)
3. Silver barb (**Barbonymus gonionotus**)
4. Nile tilapia (**Oreochromis niloticus**)

The animals were collected from three different locations along the Kwai Noi River during the dry season (January to March), a period when pollutants may concentrate due to lower water flow. Sampling was carried out in accordance with the procedures outlined by FAO and WHO (Codex Alimentarius Commission, 2003) to ensure the integrity of the specimens. In each location, three replicates of each species were collected to ensure representative sampling. The specimens were washed with deionized water to remove any external contaminants, packed in clean polyethylene bags, and transported to the laboratory on ice.

2.2 Sample preparation and analysis

Once in the laboratory, the samples were prepared for metal analysis. Muscle tissue from each aquatic animal was carefully dissected using stainless steel equipment to avoid contamination. The tissue samples were then dried at 105°C until reaching a constant weight, after which they were ground into a fine powder using a mortar and pestle.

The concentration of cadmium (Cd) and lead (Pb) in the tissue samples was determined using atomic absorption spectrophotometry (AAS) following digestion by concentrated nitric acid (HNO_3). The samples were digested in a microwave digestion system at 180°C for 30 minutes to ensure the complete breakdown of organic matter and the release of heavy metals. After digestion, the samples were diluted with deionized water and filtered through a 0.45 µm filter prior to AAS analysis.

2.3 Data analysis

The concentrations of cadmium and lead in the aquatic animal samples were expressed in mg/kg of dry weight. The data were analyzed using descriptive statistics, including mean, standard deviation, and range, to provide an overview of heavy metal contamination in each species. Additionally, the mean concentrations of Cd and Pb were compared against maximum permissible limits (MPLs) set by the European Commission (European Commission, 2006) and the Codex Alimentarius for food safety.

2.4 Risk assessment

To evaluate the potential health risks associated with the consumption of these aquatic animals, a risk assessment was conducted. CDI stands for Chronic Daily Intake. It is a term used in toxicology and risk assessment to quantify the average daily exposure to a contaminant over a specific period, usually related to chronic exposure scenarios (exposure lasting longer than 30 days). Equation (1) is based on the method described by (United States Environmental Protection Agency, 2000)

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{1}$$

where:

- C = Concentration of the contaminant in the medium (e.g., soil, water, air).
- IR = Intake rate (the amount of medium consumed per day).
- EF = Exposure frequency (the number of days the exposure occurs per year).
- ED = Exposure duration (the number of years of exposure).
- BW = Body weight of the individual (in kg).
- AT = Averaging time (typically the number of days over which the exposure is averaged, often years converted to days).

The health risk was assessed by calculating the Hazard Quotient (HQ) for each metal. HQ is a measure that assesses the potential risk posed by a single substance. It compares the estimated exposure level of a substance to a reference dose (the amount considered safe). Risk characterization is an estimate of the health effects of consuming food in areas contaminated with cadmium and lead using the following formula 2 (United States Environmental Protection Agency, 2000).

$$HQ = \frac{CDI}{RfD} \tag{2}$$

HQ < 1: The exposure is below the reference dose, suggesting no significant risk.
HQ > 1: The exposure exceeds the reference dose, indicating potential risk.

2.5 Ethical considerations

This study complied with ethical guidelines for environmental and health research. All procedures for the collection and analysis of aquatic animals were carried out in accordance with international environmental safety standards. Informed consent was obtained from local communities prior to collecting samples from community-shared water resources, and efforts were made to ensure that the research results would be shared with stakeholders to enhance awareness and promote safer consumption practices.

3. Results and Discussion

3.1 Health risk assessment results

Sample size of consumers in the survey to assess the amount of aquatic animals consumed per day by the public. The sample size was calculated to estimate the population average from the survey on fish consumption rates of Thai people. The average was 0.079± 0.010 kg/day.

$$n = \frac{1.96^2 \times 0.0102^2}{\left(0.079 \times \frac{3}{100}\right)^2}$$

The result is n = 68.39 when e is equal to 3 percent of the mean. Therefore, data collection must be divided into 70 people per station for the assessment of health risks from consuming aquatic animals contaminated with cadmium and lead. The sampling station was collected at Kwai Noi River, Makham Sung Subdistrict, Mueang Phitsanulok District, at coordinates 16° 45' 43.55"N 100° 7' 15.54"E.

1. Results of cadmium and lead analysis in aquatic animals at sampling station, by collecting samples of 4 types of aquatic animals that local people like to consume, namely, freshwater shrimp, pond snails, silver barb, and Nile tilapia. The analysis results showed that freshwater shrimp had the highest cadmium and lead contamination values, with average values of 0.049 mg/kg and 0.035 mg/kg, respectively. The next highest values were pond snails, with cadmium and lead contamination values, with average values of 0.021 mg/kg and 0.035 mg/kg, respectively. Silver barb was found to have only lead contamination values, with an average value of 0.035 mg/kg. Nile tilapia was not found to be contaminated with either cadmium or lead. When compared to the Thai food standards, which require cadmium contamination not to exceed 0.20 mg/kg and lead not to exceed 1 (European Commission, 2006), it was found that all samples of aquatic animals had contamination values not exceeding the standard values (Table 1). The detection limit for Cd and Pb in this study was determined as 0.002 mg/kg and 0.007 mg/kg, respectively. The limit of detection (LOD) values presented in Table 1 refer to the minimum concentration detectable by the analytical method used.

Table 1. The results of the analysis of the amount of cadmium and lead accumulated in aquatic animals.

No.	**Aquatic animal species**	**Analysis results**	
		Cadmium (mg/kg)	**Lead (mg/kg)**
1	Freshwater shrimp	0.049 ± 0.005	0.035 ± 0.005
2	Pond Snail	0.021 ± 0.004	0.035 ± 0.003
3	Silver Barb	N.D.	0.035 ± 0.006
4	Nile Tilapia	N.D.	N.D.

Note: N = 5; LOD for Cd = 0.002 mg/kg, Pb = 0.007 mg/kg

2. The results of the study of food consumption behavior of people in the area around sampling station found that the majority of the sample was female, 74.28%. Age ranged from 46 to 50 years, 34.28%. Weight ranged from 55 to 70 kilograms, 51.08% of the sample had an average weight of 65.31 kg, with males having an average weight of 60.43 kg and females having an average weight of 68.71 kg. They were Buddhists. Marital status is a couple 78.5%, education level mostly completed primary school 92.85%, family members are between 3-5 people 71.42%, main occupation is rice farming 32.14%, average income per year more than 30,000 baht 81.51%, most have lived in the area since birth 84.01%, duration of time that sample group live in the area the most 71.42% live in the area more than 30 years. Utilization of sampling station mostly use water for agriculture 85.39%, bring water to wash various containers and wash the body 46.09 and 18.76% respectively.

The majority of the sample group cooked at home (86.41%) and went to buy the ingredients themselves (71.54%). In cooking, it was found that most of the sample group cooked in the family (73.71%). The frequency of eating out of the house of the sample group was found to be eating with the family at home (88.56%).

The consumption behavior of aquatic animals found that the sample group liked to consume fresh water shrimp (73.11%), followed by Nile tilapia, silver barb, and pond snails (67.13, 33.69, and 25.96%, respectively). The sample group consumed aquatic animals from sampling station (81.97%). The source of aquatic animals consumed was mostly purchased from within the village/sub-district, caught from sampling station (73.21%). The frequency of consuming aquatic animals was between 0 and 5 meals/week (59.10%). The next sample group consumed aquatic animals between 5 and 10 meals/week (23.82%). The average volume sample's consumption per meal was 107 g (United States Environmental Protection Agency, U.S. EPA average of 227 g/day). Overall, the sample's average consumption was 6.1 meals/week or 93.24 g/day, and the 90th percentile aquatic animal consumption was 11 meals/week or 168.14 g/day.

3. Health risk assessment from consuming aquatic animals of people in the area around sampling station

3.1.1 Health risk assessment from cadmium

Assessment of the risk from cadmium exposure to the body through consuming aquatic animals. The CDI value was calculated from consuming aquatic animals. It was found that the CDI value of consuming freshwater shrimp was 0.127 micrograms/kilogram of body weight/day and the CDI value of consuming pond snails was 0.055 μg/kg/day (Table 2).

Table 2. Results of CDI values of aquatic animals at sampling station.

Samples	C (mg/kg)	CF (μg/kg)	IR (g/day)	EF (day/year)	ED (year)	BW (kg)	AT (day)	CDI (μg/kg/day)
shrimp	0.0493	0.87	168	323	30	65.3	10950	0.127
snail	0.0214	0.87	168	323	30	65.3	10950	0.055

Risk Characterization in the case of non-carcinogenic contaminants was calculated by dividing the CDI value of each aquatic animal by the RfD value. It was found that no aquatic animal had a HQ value greater than 1, indicating that people who like to consume aquatic animals at sampling station have no chance of being affected by health effects from cadmium contamination in aquatic animals. The HQ values of small shrimp and snails were 0.127 and 0.055, respectively (Table 3).

Table 3. Results of calculation of Hazard Quotient (HQ) values in aquatic animals at sampling station.

Samples	CDI (μg/kg/day)	RfD (mg/kg/day)	HQ
shrimp	0.127	1×10^{-3}	0.127
snail	0.055	1×10^{-3}	0.055

3.1.2 Health risk assessment from lead

From the analysis of lead contamination in aquatic animals, it was found that there were 3 types of aquatic animals that were contaminated with lead, with the same amount of 0.0347 μg/kg : freshwater shrimp, pond snails and silver barb. Because lead is a carcinogen, the U.S. EPA has not specified the amount of lead that can be safely consumed throughout human life (RfD) because many studies have found that lead cannot indicate a clear threshold value (Centers for Disease Control and Prevention, n.d.). In assessing the health risk to the public, the assessment method used the standard values set by JECFA as follows:

1) Tolerable daily intake (TDI) is 3.60 μg/kg/day or 235.1 μg/day (average weight 65.3 kilograms) and

2) Provisional tolerable weekly intake (PTWI) is 25.00 μg/kg of body weight, 1 kg/day or 1,632.50 μg/week (Food Standards Agency, 2009)

In general, the average consumption of aquatic animals per meal of the sample group was 107 g, 6.1 meals/week or 93.24 g/day or 0.093 kg/day. The lead contamination value of aquatic animals was 34.70 µg/kg. Therefore, people who consume aquatic animals will receive an average of 3.23 micrograms of lead per day, which is 63 times less than the TDI value.

4. Health risk management with public participation by applying knowledge management methods

Makham Sung Subdistrict, Mueang District, Phitsanulok Province was selected for knowledge management because it is the area with the highest amount of lead. Knowledge management process was applied as a tool to find ways to live safely with chemically contaminated environments. The participants in the knowledge management process consisted of 20 stakeholders with cadmium and lead contamination problems in the area. The results of the knowledge management are as follows:

1) Knowledge Management Direction (Knowledge Vision; KV) The participants jointly set goals for health risk management, with the objective of enabling people living in the area around Makham Sung Subdistrict, Mueang District, Phitsanulok Province to live their lives normally and safely. The meeting resolved that "Solving the cadmium and lead contamination problem in Location 6 in the short term cannot be solved. The method that will allow people living in the area around Location 6 to live safely, we will exchange knowledge with each other to find ways to manage risks in the community so that people can live safely."

2) Knowledge Sharing (KS) The participants in the knowledge management process exchanged knowledge with each other. The meeting proposed the following solutions:

Community leaders and public health volunteers: The following solutions were proposed:

1. Public health agencies in the area should inform the local people about the dangers of exposure to cadmium and lead.

2. Community leaders and public health volunteers request support for knowledge about the toxicity of chemicals and methods of self-protection from the Public Health Office of Phitsanulok Province so that public health volunteers can pass on their knowledge to the local people.

Local public health officials: The following solutions were proposed:

1. Request support for knowledge on how to deal with diseases caused by cadmium and lead poisoning so that public health officials can treat, prevent, and promote the health of people at risk in the area.

2. Relevant agencies should allocate a budget to implement measures to control and prevent exposure to cadmium and lead.

2.1 A community plan should be created in each village to promote health.

2.2 Organize an academic team to provide knowledge to local leaders so that they have knowledge and understanding about the dangers of exposure to cadmium and lead.

2.3 Coordinate with school administrators to integrate content about the dangers of cadmium and lead into health education subjects.

3. Knowledge Assets: KA is a process of creating a knowledge base. The researcher summarized the information from the knowledge management process for the meeting to create a community plan by obtaining a community plan for risk surveillance and inspection to be a health surveillance of the public. Environmental surveillance consists of collecting samples of water, sediment, and soil, continuously and comprehensively analyzing in all areas, monitoring the accumulation of cadmium and lead in food, and monitoring the health of the public in the area around sampling station at Makham Sung Subdistrict, Mueang District, Phitsanulok Province by testing the urine of people in the area in the risk group and the group that has not been tested. The results of the analysis of the amount of cadmium and lead accumulated in aquatic animals at sampling station at Makham Sung Subdistrict, Mueang District, Phitsanulok Province by collecting samples of aquatic animals that people in the area like to consume, a total of 4 types: freshwater shrimp, pond snails, silver barb, and tilapia. The results of the analysis found that freshwater shrimp had the highest cadmium and lead contamination values, with an average value of 0.0493 mg/kg and 0.0347 mg/kg, respectively. The next highest value was the river snail, which had

cadmium and lead contamination values. The average values were 0.0214 mg/kg and 0.0347 mg/kg, respectively. The silver barb was found to have a contamination value of only lead with an average value of 0.0347 mg/kg. This is because both freshwater shrimp, pond snails and silver barb like to hide under rocks or cling to plants. They like to live in still or slowly flowing water, murky water, not more than 1 meter deep, with organic matter piled up. They will eat food such as fresh and rotten algae, rotten leaves and grass, as well as rotten organic remains and sediment that sinks to the surface of the soil. Their habitats tend to be in muddy areas, causing freshwater shrimp, pond snails and silver barb to have the opportunity to accumulate heavy metals in their bodies, which is in accordance with the principles of Bio-Magnification and Bioaccumulation (Botkin & Keller, 1998). As for Nile tilapia, it was found that it was contaminated with both cadmium and lead when compared to the Thai food standard, which requires cadmium contamination not to exceed 0.2 mg/kg. and lead content not exceeding 1 milligram per kilogram (European Commission, 2006) found that all samples of aquatic animals had contamination values not exceeding the standard values.

The majority of the sample, 84.01%, had been living in the area since birth, with only 15.99% moving from other areas. The duration of the majority of the sample, 71.42%, had been living in the area for more than 30 years, making the sample at risk of health effects from exposure to cadmium and lead through the food chain for a long time. Normally, the obvious health symptoms of those exposed to cadmium and lead will begin to become apparent after approximately 30 years of exposure to cadmium (United States Environmental Protection Agency, 2000). Cooking: Most of the sample cooked at home, accounting for 85.39%. The sample group went to buy the ingredients themselves, 71.54%, and the family cooked the food, 73.71%. If the sample group had knowledge about choosing ingredients that were free from chemical contamination to cook, the sample group would be able to eat food safely. Risk Characterization in the case of non-carcinogenic contaminants There is a method to find by dividing the CDI value of each type of aquatic animal by the RfD value. It was found that no type of aquatic animal has a Hazard Quotient value greater than 1, indicating that people who like to consume aquatic animals at sampling station in Makham Sung Subdistrict, Mueang District, Phitsanulok Province do not have the opportunity to be affected by health effects, such as fragile bones and kidney failure. The analysis of lead contamination in aquatic animals found that there were 3 types of aquatic animals that were contaminated with lead, with the same amount of 0.0347 mg/kg, namely, small shrimp, snails and carp. Because lead is a carcinogen, the EPA has not specified the amount of lead that can be safely consumed throughout a human life (RfD). Many studies have found that lead cannot indicate a clear level of tolerance (Threshold) (Centers for Disease Control and Prevention, n.d.). Even though the amount of lead contamination does not exceed the TDI value, if you can avoid consuming food contaminated with lead, you should avoid it. If you cannot avoid it, you must reduce the size and frequency of consumption. The researcher returned the research data through the health forum. To all seminar participants, knowledge was provided on cadmium and lead contamination in the food chain and the environment, health risks from cadmium and lead contamination through consumption, methods to reduce the risk of cadmium and lead contamination from consumption, and recommendations for safe food consumption. The seminar participants were also informed, along with leaflets distributed to seminar participants. The community participation model was based on content, namely, people participating in development by participating in decision-making and planning, participating in actions, participating in receiving benefits, and participating in evaluating the results of actions.

3.2 Summary of the results of the health risk assessment

From the analysis of the amount of cadmium and lead accumulated in aquatic animals caught from sampling station in Makham Sung Subdistrict, Mueang District, Phitsanulok Province, 4 species, it was found that small shrimp had the highest cadmium and lead contamination values. When compared to the Thai food standards, which must have cadmium contamination not exceeding 0.20 mg/kg and lead not exceeding 1.00 mg/kg, it was found that all aquatic animal samples had contamination values not exceeding the standard values. However, people should avoid consuming aquatic animals contaminated with these chemicals. However, if it is unavoidable, the size and frequency of consumption must be reduced. In order to minimize the amount of chemicals absorbed into the body, for the management of public health risks, continuous monitoring of cadmium and lead contamination in aquatic animals and the environment should be conducted to monitor public health.

Risk Characterization In the case of non-carcinogenic contaminants, the method used is to divide the CDI value of each aquatic animal by the RfD value. It was found that no aquatic animal had a Hazard Quotient value greater than 1 , indicating that people who like to consume aquatic animals at sampling station in Makham Sung Subdistrict, Mueang District, Phitsanulok Province have no potential health risk of being affected by health effects.

The analysis of lead contamination in aquatic animals found that there were 3 aquatic animals contaminated with lead, with the same amount at 0.0347 mg/kg: freshwater shrimp, pond snails, and silver barb. Since lead is a carcinogen, and the EPA has not established a safe lifetime intake level (RfD), several studies have found that lead cannot provide a clear Threshold (Centers for Disease Control and Prevention, n.d.). Even if lead contamination levels do not exceed the TDI, consuming food contaminated with lead should be avoided. If unavoidable, consuming food should be reduced in size and frequency.

4. Conclusions

This study concluded that although cadmium and lead were detected in aquatic animals consumed by the local population in Makham Sung Subdistrict, Phitsanulok, Thailand, the contamination levels were within the acceptable limits set by Thai food safety standards. Freshwater shrimp and pond snails showed the highest contamination levels, but the Hazard Quotients (HQ) for all species were below 1, indicating no significant non-carcinogenic health risks from consumption. However, given that lead is a carcinogen with no established safe threshold for lifetime exposure, it is recommended that consumption of contaminated species be minimized in frequency and portion size to reduce potential long-term risks. The study underscores the importance of continuous environmental monitoring and community engagement in managing health risks associated with chemical contamination. Public health initiatives should focus on educating local populations about safe consumption practices and reducing exposure to cadmium and lead through knowledge sharing and risk management strategies.

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Conflict of Interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Ethical Approval

The study was approved by 2/12/2023 Number of ethics COA No. 478/2022 IRB No. P2-0406/2565

Publication Ethic

Submitted manuscripts must not have been previously published by or be under review by another print or online journal or source.

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