Research Article Open Access

The safety of animal-derived food products in areas of technogenic pollution

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Submission Date: September 13th, 2024; **Acceptance Date:** October 6th, 2024; **Publication Date:** October 11th, 2024

Please cite this article as: Sevoyan G. G., Minasyan S. H., Yesayan T. A., Babayan B. G., Avetisyan S. S., Yesayan H. A. The Safety of Animal-derived Food Products in Areas of Technogenic Pollution. *Functional Foods in Health and Disease* 2024; 14(10): 704-712. DOI: https://doi.org/10.31989/ffhd.v14i10.1484

ABSTRACT

Background: Food safety has been a concern since ancient times. In the 21st century, technogenic pollution from harmful natural and synthetic chemicals poses a significant threat to food safety. These substances can enter the various consumption chains and to be transmitted from organism to organism, ultimately reaching the human body through both animal-sourced and plant-sourced food products. Animal-sourced food is the main source of protein and essential compounds. Therefore, assessing the safety of animal-sourced food products, which are produced and consumed by populations in areas of technogenic pollution (such as factory surroundings and military conflict zones) is crucial.

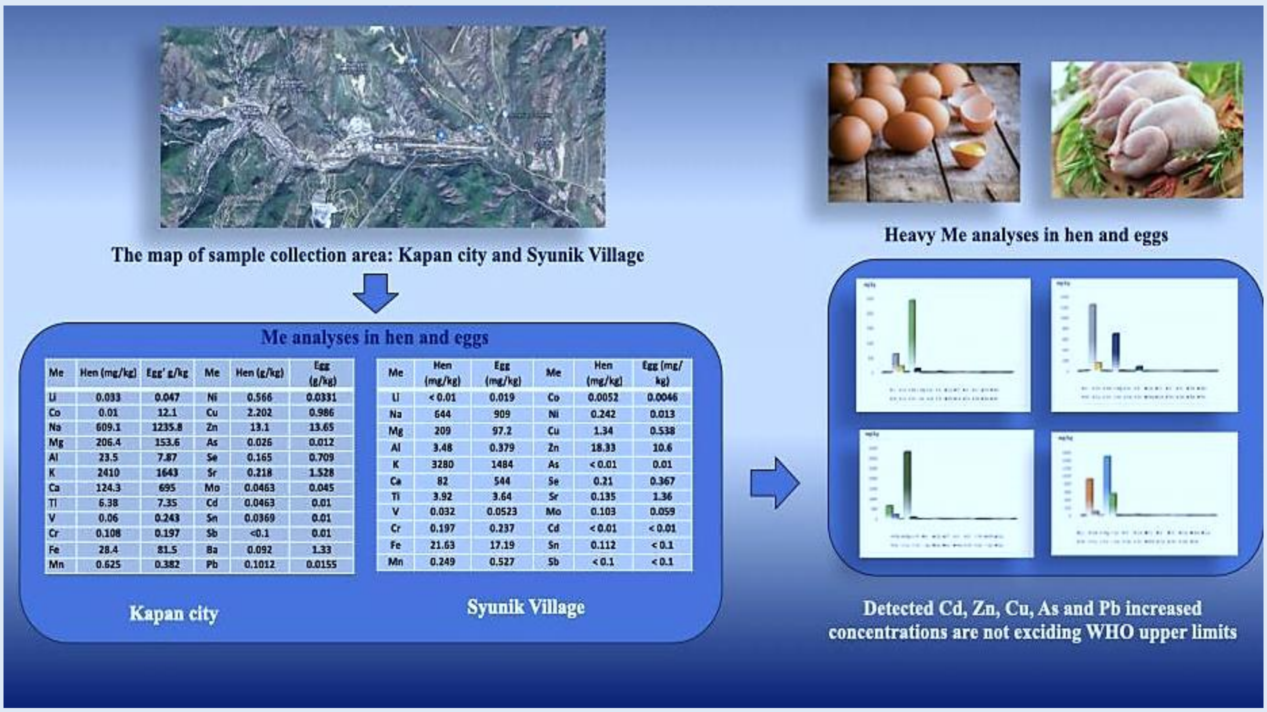
Objectives: The primary goal of this research was to study the contamination of animal-sourced foods (eggs and hen) produced in urban area of one of regions of Armenia's regions, which has a heavy legacy of industrial pollution.

Context and purpose of this study: This study aimed to assess and compare the concentrations of alkaline, alkaline-earth and transition elements, including heavy metals, in common animal-sourced food products produced in Kapan city, Armenia, and Syunik village, which borders Kapan city. To achieve this, poultry (hen) and egg samples were analyzed using inductively coupled plasma-mass spectrophotometry (ICP-MS) to detect the following heavy metals: Li; Na; Mg; Al; K; Ca; Ti; V; Cr; Fe; Mn; Co; Ni; Cu; Zn; As; Se; Sr; Mo; Cd; Sn; Sb; Ba and Pb.

Results: The concentrations of heavy metals were elevated in all animal-sourced food samples from Syunik Village and Kaplan City. Similarly, general concentrations of alkaline and alkaline-earth metals were also increased. Comparative analysis revealed that concentrations of all studied elements were lower in Syunik Village than in Kaplan City. Notably, all detected levels were below the maximum permissible concentrations (MPC).

Conclusions: Elevated concentrations of heavy metals were observed in all studied egg and hen samples from Syunik village and Kapan city. This increase is likely attributed to the mining industry development in the Syunik region. Although the detected levels are below the maximum permissible concentrations established by the World Health Organization (WHO), continuous monitoring of heavy metal concentrations in this area is recommended to mitigate potential health risks associated with chronic consumption of locally produced eggs.

Keywords: food safety, animal-sourced food, heavy metals, technogenic pollution, remediation.



Graphical Abstract: The safety of animal-derived food products in areas of technogenic pollution

INTRODUCTION

Food safety is a major global concern that persists into the 21st century [1]. This problem is exacerbated by the fact that environmental degradation and diminished food quality are frequently linked to certain aspects of technological advancement and industrialization [2-3].The core of this problem lies in chemical contamination, specifically radiation pollution, affecting environmental media (soil, air, and water) near chemical industry facilities [4-5].The urgency of this problem is felt worldwide, spanning economically developed countries (EU, Canada, China, etc.) and developing nations with limited financial resources (African and Middle Eastern countries, etc.). Political and technological disparities further complicate its manifestations [6-7]. As a result, ecotoxicological evaluation and revision of new technologies are now a necessity in the 21st century [8-9]. Similar to other former USSR countries, Armenia has a rich history of chemical and industrial technologies, boasting prominent establishments such as the Nairit chemical factory, mines in Syunik and Kotayk regions, and Kirovakan's Chemical Factory. Due to chemical contamination, several regions in Armenia face significant health risks, jeopardizing the well-being of the population [10-11].

In areas affected by technogenic pollution, ecotoxicology, and healthcare problems are interconnected due to intricate food chains that transport toxic substances from the environment to humans. Plant-sourced foods, being in direct contact with contaminated soil, water, and air, are particularly susceptible [12]. The contamination of animal-derived foods with environmental chemical pollutants can occur through direct contact between animals and pollutants or indirectly through the consumption of contaminated plants. Herbivores ingest plants that have accumulated hazardous substances, such as heavy metals and transitional elements, which are then transferred to animal-sourced food products [13-14]. Humans are exposed to a wide range of hazardous compounds in technogenically polluted areas through their daily consumption of plant-sourced and animal-sourced foods. Animal-derived products (meat, eggs, milk, etc.) are key providers of essential proteins, including vitamin B12 and taurine, and important micronutrients [15-16]. Deficiencies in specific microelements lead to distinct diseases and an overall decline in quality of life. Conversely, excessive concentrations of micronutrient elements cause different types of diseases, all related to enzymatic regulation disruptions in cellular metabolic pathways. Certain transitional elements, such as Cr(VI) compounds, Pb, and Cd, exhibit physiologically toxic (chronic and acute), genotoxic, cancerogenic, and teratogenic effects [17-19]. Additionally, elements like Cu and Zn demonstrate concentration-dependent microbial growth promotion and antimicrobial properties [20-21]. This research focuses on assessing potential risks of contamination in animal-sourced food products from technogenically polluted areas in Armenia.

MATERIALS AND METHODS

Sample collection: A total of four sampling points were established in the Syunik region of Armenia, specifically in Kapan City and Syunik Village (Fig. 1). This region was selected due to its unique combination of industrial activity, mineral-rich soil, and exceptional biodiversity. As a major agricultural region, it plays a vital role in Armenia's economy [22-24]. The samples collected included poultry products (poultry and eggs) and milk.

Figure 1. The map of the territory of the sample collection.

Metals assessment: The presence of alkaline, alkaline-earth, and transition heavy metals in the collected samples was determined using ICP-MS (ELAN 9000, PerkinElmer), a sensitive and accurate analytical technique [25-27]. The homogenization step employed a BIoSan Homogenizer RCP-24. Subsequently, 65-70% double distilled nitric acid was added, and samples were subjected to microwave digestion (10-15 minutes, 180 °C). After cooling and adjusting acidity to pH < 2, metal analysis was performed using ICP-MS to detect: Li, Na, Mg, Al, K, Ca, Ti, V, Cr (III and VI), Fe, Mn, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Cd, Sn, Ba, and Pb [28-30].

Statistical assessment: The statistical assessment of experimental reliability employed widely accepted methods [31]. Each experiment was conducted in five series with triplicate samples. Data analysis utilizing MS Excel yielded: The Standard Error of the Means (SEM) was ± 0.23–0.37. The significance was tested by the application of the Student t-test and the mean of *p*-value was estimated as less than 0.05.

RESULTS

The results of the assessment of heavy metals in samples of eggs and hens collected from Kapan City are presented in Table 1. The obtained results revealed increased heavy metal concentrations in all Kapan city samples. The study then progressed to analyze metal content in samples from Syunik village, as shown in Table 2

Table 1. The assessment of metals in samples of eggs and hens in Kapan city.

Me	Hen (mg/kg)	Egg g/kg	Me	Hen (g/kg)	Egg (g/kg)
Li	0.033	0.047	Ni	0.566	0.0331
Co	0.01	12.1	Cu	2.202	0.986
Na	609.1	1235.8	Zn	13.1	13.65
Mg	206.4	153.6	As	0.026	0.012
Al	23.5	7.87	Se	0.165	0.709
K	2410	1643	Sr	0.218	1.528
Ca	124.3	695	Mo	0.0463	0.045
Ti	6.38	7.35	Cd	0.0463	0.01
V	0.06	0.243	Sn	0.0369	0.01
Cr	0.108	0.197	Sb	<0.1	0.01
Fe	28.4	81.5	Ba	0.092	1.33
Mn	0.625	0.382	Pb	0.1012	0.0155

Table 2. The assessment of metals in samples of hen and egg in Syunik Village

Me	Hen (mg/kg)	Egg (mg/kg)	Me	Hen (mg/kg)	Egg (mg/kg)
Li	< 0.01	0.019	Co	0.0052	0.0046
Na	644	909	Ni	0.242	0.013
Mg	209	97.2	Cu	1.34	0.538
Al	3.48	0.379	Zn	18.33	10.6
K	3280	1484	As	< 0.01	0.01
Ca	82	544	Se	0.21	0.367
Ti	3.92	3.64	Sr	0.135	1.36
V	0.032	0.0523	Mo	0.103	0.059
Cr	0.197	0.237	Cd	< 0.01	< 0.01
Fe	21.63	17.19	Sn	0.112	< 0.1
Mn	0.249	0.527	Sb	< 0.1	< 0.1

The experiments revealed similarities between samples from Kapan city and Syunik village, with elevated concentrations of alkaline, alkaline-earth, and heavy metals observed in all studied samples. A comparative analysis of egg and hen samples showed no significant differences in measured metal concentrations. However, a notable trend emerged: transition metal concentrations were consistently lower in Syunik village samples compared to Kapan city samples (Fig. 2-5).

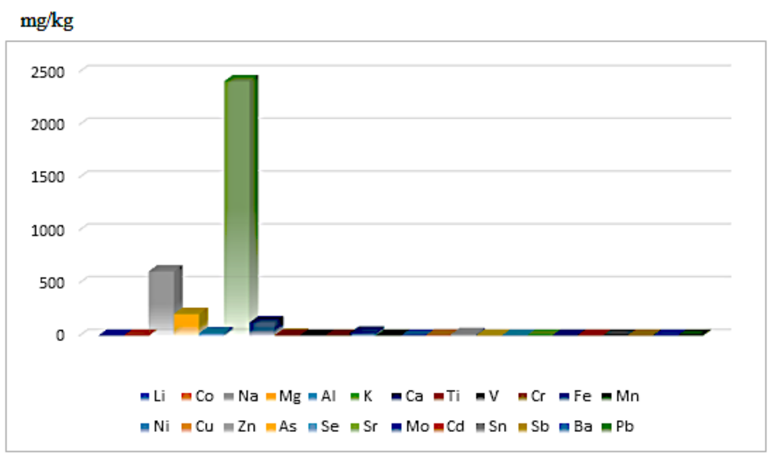


Figure 2. The analysis of metal content in hen samples from Syunik Village

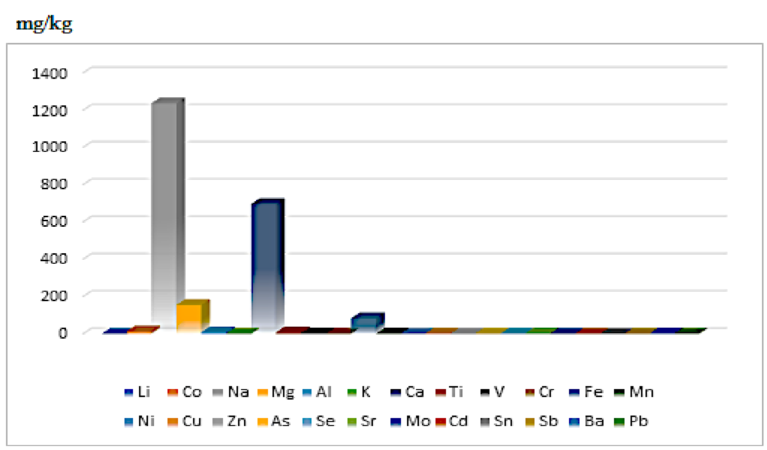


Figure 3. The analysis of metals in eggs samples from Syunik Village.

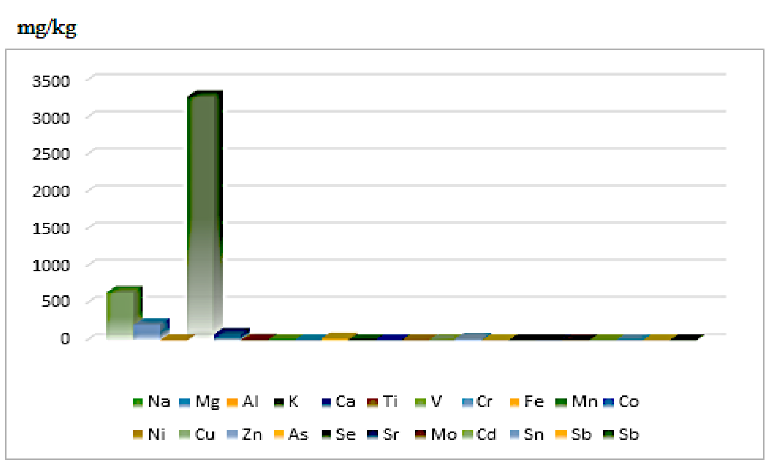


Figure 4. The analysis of metals in hen samples from Kapan City.

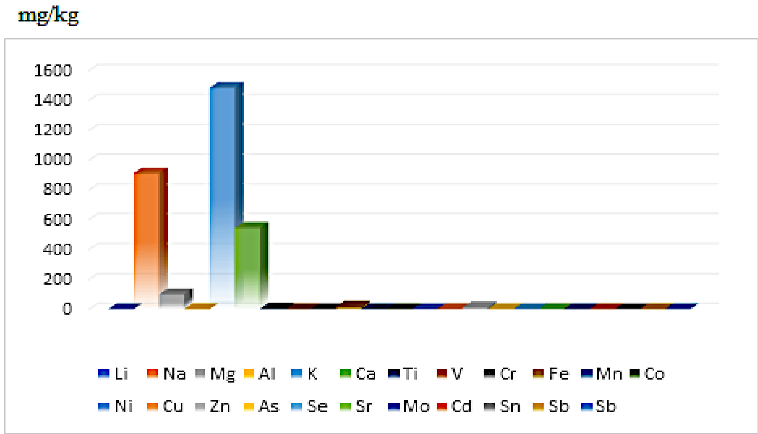


Figure 5. The analysis of metals in eggs samples from Kapan City.

DISCUSSION

This study investigated the consistency of 26 chemical elements in hen and eggs from Kapan city and Syunik Village. The results showed higher concentrations of heavy metals in Kapan city samples compared to Syunik Village samples. Micronutrient element concentrations were slightly higher in Syunik Village samples, potentially due to geological features and soil/water chemistry. Notably, all measured means of heavy metals and trace elements remained below the maximum permissible concentrations (MPCs) set by the World Health Organization (WHO) [32]. Specifically: Pb are 0.3 mg/kg for eggs and 0.5 mg/kg for hen; Cd: 0.01 mg/kg for eggs and 0.05 mg/kg for hen; for as: 0.1 mg/kg both for eggs and hen; for Cu: 3.0 for eggs and 5.0 for hen; Zn: 50.0 for eggs and 20.0 for hen [32]. The highest concentrations were observed for Pb, Cd, As, Cu, and Zn. These increased levels may be attributed to mining activities in the Syunik region, releasing excessive concentrations of these elements into the environment. The presence of these heavy metals poses a significant threat to human health, animals, and biodiversity due to their non-selective inhibitory effects on enzymes [33]. Furthermore, heavy metals like Cd have negative impacts on various cell types, entering ecological systems through natural and anthropogenic sources [35-37]. Cd's bioaccumulation in humans disrupts the antioxidant system, leading to oxidative stress, metabolic pathologies, and potential neurodegenerative diseases. Chronic consumption of contaminated food products increases health risks, including cardiovascular problems, respiratory pathologies, cancer, neurodegenerative diseases and mental health issues [38].

Copper (Cu) and Zinc (Zn) are essential micronutrients that play a crucial role in maintaining normal enzymatic activity in human cells. Biochemically, they facilitate various vital processes, including cytochrome system function, insulin biosynthesis, immune system regulation, wound healing, and taste and smell recognition. These micronutrients are vital not only for human health but also for the well-being of other organisms [39-40].

However, excessive accumulation of Cu and Zn can lead to a range of pathologies. For instance, high concentrations of these elements can suppress normal absorption of Cu and iron. Moreover, excessive Zn can be toxic to plants, bacteria, invertebrates, and vertebrates. Interestingly, Zn's properties as an apoptotic activator are being explored for potential applications in cancer treatment [41-42]. While Zn's acute toxicity is relatively low, chronic consumption of excessive amounts through food products can cause health problems [43-44]. In contrast, lead (Pb) is highly toxic to humans and organisms, primarily through protein denaturation and enzyme inhibition. The systemic effects of Pb exposure include neurotoxicity, intestinal toxicity, and reproductive system disruption [45-46]. Given the severe health implications of Pb exposure, monitoring its concentrations in food products is crucial. Ensuring safe levels of Pb and other heavy metals in the food supply is essential for protecting public health. Therefore, regular monitoring and regulation of heavy metal concentrations in food products are necessary to prevent adverse health effects.

CONCLUSION

This study presents the first systematic analysis of heavy metal concentrations in animal-derived food products from Syunik village and Kapan city, located in one of Armenia's most significant agrarian regions. Our research reveals a notable increase in heavy metal and toxic trace element concentrations in both territories. The prevalence of Zn, Cu, Cd, Pb, and As is likely attributed to active mining activities in the region. Comparatively, Kapan city showed higher concentrations than Syunik village, potentially due to proximity to mining sites and urban vehicle emissions. Encouragingly, all measured means of heavy metals in egg and hen samples fell below estimated Maximum Permissible Concentrations (MPC). This may be attributed to the breeding and feeding practices of local farmers, minimizing the use of contaminated plant-sourced feeds. However, chronic consumption of food products with elevated heavy metal levels poses significant health risks. Therefore, continued monitoring of heavy metals and trace elements in this region is crucial to ensure public health and safety.

Abbreviations: MPC, maximum permissible concentration; ICP-MS, induction-coupled plasma-mass spectrophotometry; ROS, reactive oxygen species; WHO, World Health Organization.

Author's Contributions: All authors contributed to this study. No competing interests were disclosed.

Acknowledgments: We're very thankful to all the staff of laboratory of Applied Biology and Ecology of Research Institute of Biology, YSU.

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