Spatio-Temporal Analysis of Heavy Metal Contamination In Bovine Drinking Water: Assessing Environmental Risks In A Developing Agro-Industrial Hub

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Abstract- *This research aimed to quantify the concentrations of key heavy metals—specifically Arsenic (As), Lead (Pb), Cadmium (Cd), Mercury (Hg), Copper (Cu), Chromium (Cr), and Zinc (Zn)—in water sources utilized by livestock. A total of 70 samples were strategically harvested from diverse geographic locations across the Western region, encompassing urban, semi-urban, and rural environments. Sampling points included borewells, open wells, river/canal systems, and municipal supplies. Analysis was performed via Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), with results benchmarked against World Health Organization (WHO, 1998), European Union (EU, 2020), and Bureau of Indian Standards (BIS, 2012) guidelines.*

Findings revealed that while As and Pb concentrations approached the maximum residual limits (MRL) defined by the WHO and EU, they remained within the permissible thresholds of the BIS. Concentrations of Cd, Hg, Cu, Cr, and Zn were consistently below all international and domestic safety standards. Notably, urban and semi-urban water sources exhibited significantly higher heavy metal loads compared to rural sites. The study underscores the necessity of continuous environmental monitoring to mitigate health risks to dairy livestock and, by extension, human consumers through the food chain.

Keywords: Heavy metals, ICP-MS, Water quality, Livestock hydration, Western region.

I. INTRODUCTION

Heavy metal contamination poses a persistent threat to biological systems due to its inherent toxicity and high potential for bioaccumulation within the food web. When consumed in excess of physiological requirements, these elements trigger deleterious health effects in both humans and animals. These pollutants are introduced into the biosphere through various pathways, including fossil fuel combustion, mineral extraction, agricultural runoff, and transport emissions. Furthermore, the integrity of groundwater systems is increasingly compromised by anthropogenic overexploitation and land-use intensification (Caspers, 1981).
In regions characterized by high population density, groundwater vulnerability is heightened. Industrial effluents, whether discharged intentionally or through accidental leakage, serve as primary vectors for chemical contamination (Merkel et al., 2022). The presence of hazardous contaminants significantly diminishes the utility of water for both commercial and domestic applications. While certain elements like Cu, Fe, Mn, Ni, and Zn are essential micronutrients for biological metabolic processes, they become toxic at elevated concentrations. Conversely, elements such as As, Hg, Cd, Cr, and Pb serve no biological function and are hazardous even at low levels.

The movement of heavy metals into groundwater is largely driven by surface water infiltration and soil leaching, with the mobility of these toxins being heavily influenced by local soil characteristics. The global surge in urbanization, industrial expansion, and intensive agriculture has catalyzed an increase in environmental pollution across air, soil, and aquatic ecosystems (Hassanzadeh et al., 2011). Because of their environmental persistence and toxicity, heavy metals remain among the most critical environmental pollutants. While they can occur naturally, the current spike in environmental concentrations is largely attributed to anthropogenic activities, including industrial processing, domestic waste mismanagement, and vehicular emissions (El Ayni et al., 2011). Heavy metals are ubiquitous in almost all water sources, often originating from the natural erosion and weathering of the earth’s crust (Newcomb and Rimstidt, 2002). However, human activities—such as urban sewage discharge, industrial manufacturing, and the use of wastewater for irrigation—also significantly degrade water quality. These anthropogenic pollutants can leach into aquifers, leading to the contamination of vital groundwater supplies (Charles worth and Lees, 1999).In light of these environmental risks, this study was designed to evaluate the levels of heavy metal concentration in the drinking water provided to livestock within the Western region of Maharashtra.

II. MATERIALS AND METHODS

This research aimed to quantify the levels of Arsenic (As), Lead (Pb), Cadmium (Cd), Mercury (Hg), Copper (Cu), Chromium (Cr), and Zinc (Zn) in animal drinking water within Maharashtra's Western region. Samples were sourced from diverse locations, including borewells, open wells, canals, rivers, and municipal supplies. The study spanned six districts—Mumbai, Thane, Palghar, Pune, Satara, and Kolhapur—which were categorized into urban, semi-urban, and rural zones based on their industrial density and population.

Sampling Strategy and Site Selection

Sampling was strategically focused on areas with high contamination risks:

- Urban Areas: Samples were primarily taken near industrial hubs or effluent discharge sites.
- Semi-Urban Areas: Farms were selected from talukas (blocks) adjacent to industrial zones or major highways.
- Rural Areas: Sites were chosen that were entirely removed from industrial or urban influence to serve as a baseline.

Sample Collection and Preservation

A total of 60 water samples were collected from both organized livestock farms and individual holdings. The protocol ensured high purity and stability:

1. Preparation: 10 ml Tarson tubes were cleaned with double-distilled, deionized water and soaked overnight in 10% nitric acid (HNO_3).
2. Filtration: Samples were processed using Whatman No. 42 filter paper.
3. Acidification: To prevent metal precipitation and microbial growth, the pH was adjusted to approximately 2.0 using concentrated nitric acid (Kramer, 1994).
4. Storage: Samples were transported in iceboxes at 4°C and subsequently stored in a deep freezer at -20°C.

Analytical and Statistical Procedures

Chemical analysis was performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Mumbai Veterinary College's Department of Veterinary Public Health. To ensure scientific rigor, the resulting data were subjected to statistical analysis following the methods of Snedecor and Cochran (1994).

III. RESULTS AND DISCUSSION

Table1: Overall concentration of heavy metals(ppm) in water samples in Western region of Maharashtra

The findings presented in Table 1 reveal that arsenic concentrations in animal drinking water were significantly higher ($p < 0.01$) in urban and semi-urban zones compared to rural areas. While levels in urban and semi-urban settings approached the Maximum Residue Limits (MRL) established by the WHO (1998) and EU (2020), they remained well within the permissible limits set by the BIS (2012). Conversely, rural arsenic levels were significantly lower than all referenced international and national standards.

Geographically, Mumbai and Thane districts exhibited significantly higher ($p < 0.01$) arsenic levels within their urban sectors compared to other districts in the Western region (Tables 2 and 3). These results align with Raju et al. (2014), who found elevated but safe arsenic levels in Andhra Pradesh, and Cobbina et al. (2015) in Ghana. However, they contrast with Zodape et al. (2014), who detected no arsenic in the Goregaon suburb of Mumbai.

Lead, cadmium, and mercury concentrations followed a similar trend, with significantly higher ($p < 0.01$) levels recorded in urban and semi-urban regions than in rural ones. Despite this, lead concentrations remained below the MRLs defined by WHO, EU, and BIS. District-wise analysis further confirmed that lead levels were most prominent in the industrialized zones of Mumbai and Thane.

These observations are consistent with Mohan Kumar et al. (2016), who noted higher heavy metal concentrations in industrial residential areas of Tamil Nadu. In contrast, Singare and Fern (2009) and Hasan et al. (2016) reported lead and mercury levels exceeding CPCB standards in Mahim Creek and the Bengal coast, respectively, suggesting that localized pollution hotspots can surpass general regional averages.

While copper and zinc concentrations were significantly higher ($p < 0.01$) in urban and semi-urban areas relative to rural sites, the levels for all three metals (Cu, Cr, and Zn) remained safely below the MRLs suggested by WHO, EU, and BIS across the entire Western region.

In contrast to the localized variances observed for arsenic and lead, the concentrations of cadmium, mercury, copper, chromium, and zinc remained statistically uniform across the different districts of the Western region. The findings regarding copper and zinc align with research by Nagendrappa et al. (2009) in the Tumakuru district of Karnataka, which similarly found these metals within safe, potable limits.

Table1: Concentration of the Metals in Urban, Semi-Urban and Rural Area (Ppm) In Water Samples In Of Western Region of Maharashtra

Sr. no.	Metals	Urban area	Semi-urban area	Rural area	CD	Level of significance
1	Arsenic	$0.0162^{a}\pm 0.0013$	$0.0134^{a}\pm 0.001$	$0.0088^{b}\pm 0.00086$	0.004	**
2	Lead	$0.0121^{a}\pm 0.0006$	$0.0091^{ab}\pm 0.001$	$0.0070\ ^{b}\pm 0.005$	0.004	**
3	Cadmium	$0.00301\ ^{a}\pm 0.0001$	$0.00198\ ^{b}\pm 0.00005$	$0.00162^{b}\pm 0.0003$	0.002	**
4	Mercury	$0.0011\ ^{a}\pm 0.0002$	$0.0009\ ^{a}\pm 0.00008$	$0.0005\ ^{b}\pm 0.00003$	0.0003	**
5	Copper	$0.551^{a}\pm 0.013$	$0.473^{b}\pm 0.021$	$0.324^{b}\pm 0.017$	0.127	**
6	Chromium	$0.0281\ ^{a}\pm 0.001$	$0.0195\ ^{b}\pm 0.001$	$0.0156\ ^{b}\pm 0.001$	0.008	**
7	Zinc	$1.888\ ^{a}\pm 0.071$	$1.612\ ^{b}\pm 0.041$	$1.281^{c}\pm 0.054$	0.334	**

**- Significant at 1%level

a,b,c…mean with different superscript in a row differ significantly.

Table2: District wise concentration of As,Pb,Cd and Hg(ppm) in water samples in of Western region of Maharashtra

District	Arsenic			Lead			Cadmium			Mercury		
	Urban	Semi-urban	Rural	Urban	Semi-urban	Rural	Urban	Semi-urban	Rural	Urban	Semi-urban	Rural
Mumbai	$0.0251^{a}\pm 0.002$	---	---	$0.0168^{a}\pm 0.002$	---	---	0.00393 ± 0.0005	---	---	0.001468 ± 0.0003	---	---
Thane	$0.0214^{ab}\pm 0.001$	$0.0207^{a}\pm 0.01$	$0.0142^{a}\pm 0.001$	$0.0142^{a}\pm 0.01$	0.0119 ± 0.0003	0.0093 ± 0.004	0.00371 ± 0.0004	0.00227 ± 0.0003	0.00132 ± 0.0004	0.001318 ± 0.0001	$0.00118^{a}\pm 0.0001$	0.000341 ± 0.00003
Palghar	$0.0181^{bc}\pm 0.0005$	$0.0171^{ab}\pm 0.03$	$0.0098^{ab}\pm 0.001$	$0.0112^{b}\pm 0.01$	0.0108 ± 0.001	0.0073 ± 0.001	0.00295 ± 0.0003	0.00212 ± 0.0002	0.00181 ± 0.0006	0.001038 ± 0.0003	$0.000968^{a}\pm 0.00001$	0.000407 ± 0.00006
Pune	$0.0157^{c}\pm 0.001$	$0.0146^{b}\pm 0.01$	$0.0093^{bc}\pm 0.001$	$0.0107^{b}\pm 0.01$	0.0104 ± 0.002	0.0086 ± 0.003	0.00268 ± 0.0003	0.00188 ± 0.0003	0.00156 ± 0.0001	0.000926 ± 0.0004	$0.000872^{a}\pm 0.00004$	0.000531 ± 0.0001
Satara	$0.0093^{d}\pm 0.0002$	$0.0082^{c}\pm 0.0007$	$0.0057^{bc}\pm 0.001$	$0.0093^{b}\pm 0.006$	0.0058 ± 0.001	0.0048 ± 0.001	0.00242 ± 0.0004	0.00188 ± 0.0003	0.00176 ± 0.0003	0.000536 ± 0.00009	$0.000392^{b}\pm 0.0001$	0.000248 ± 0.00006
Kolhapur	$0.0072^{d}\pm 0.0006$	$0.0069^{c}\pm 0.0006$	$0.0045^{c}\pm 0.001$	$0.0086^{b}\pm 0.004$	0.0063 ± 0.001	0.0044 ± 0.001	0.00208 ± 0.0005	0.00183 ± 0.0001	0.00163 ± 0.0006	0.000558 ± 0.0001	$0.000455^{b}\pm 0.00004$	0.000296 ± 0.0001
Average	$0.0162^{a}\pm 0.0013$	$0.0134^{a}\pm 0.001$	$0.0088^{b}\pm 0.0008$	$0.0121^{a}\pm 0.004$	$0.0091^{ab}\pm 0.001$	$0.0068^{b}\pm 0.005$	$0.0031^{a}\pm 0.0002$	$0.0018^{b}\pm 0.0001$	$0.0017^{b}\pm 0.0001$	$0.0011^{a}\pm 0.0001$	$0.00009^{b}\pm 0.00007$	$0.00005^{b}\pm 0.00003$
CD	0.005	0.007	0.007	0.004	---	---	---	---	---	---	0.0004	---
Level of Significance	**	**	**	**	NS	NS	NS	NS	NS	NS	**	NS

**- Significant at 1%level NS-Non Significant

a,b,c…mean with different superscript in a column differ significantly.

Table 3: District wise concentration of Cu,Cr and Zn (ppm) in water samples in Western region of Maharashtra

District	Copper			Chromium			Zinc		
	Urban	Semi-urban	Rural	Urban	Semi-urban	Rural	Urban	Semi-urban	Rural
Mumbai	0.639 ± 0.05	---	---	0.0373 ± 0.001	---	---	$2.409^{a}\pm 0.1$	---	---
Thane	0.616 ± 0.09	$0.612^{a}\pm 0.05$	0.438 ± 0.09	0.0308 ± 0.003	0.0251 ± 0.005	0.0211 ± 0.002	$2.114^{ab}\pm 0.1$	$1.93^{a}\pm 0.1$	1.496 ± 0.1
Palghar	0.541 ± 0.07	$0.538^{ab}\pm 0.03$	0.347 ± 0.06	0.0282 ± 0.006	0.0213 ± 0.005	0.0182 ± 0.002	$1.911^{abc}\pm 0.1$	$1.733^{ab}\pm 0.07$	1.255 ± 0.09
Pune	0.517 ± 0.05	$0.429^{bc}\pm 0.05$	0.294 ± 0.05	0.0253 ± 0.007	0.0193 ± 0.002	0.0130 ± 0.01	$1.716^{bc}\pm 0.3$	$1.574^{abc}\pm 0.3$	1.258 ± 0.07
Satara	0.505 ± 0.04	$0.466^{bc}\pm 0.06$	0.283 ± 0.08	0.0233 ± 0.004	0.0158 ± 0.001	0.0123 ± 0.003	$1.503^{c}\pm 0.03$	$1.494^{bc}\pm 0.1$	1.315 ± 0.2
Kolhapur	0.476 ± 0.03	$0.334^{c}\pm 0.03$	0.261 ± 0.04	0.0207 ± 0.003	0.0167 ± 0.001	0.0138 ± 0.003	$1.557^{bc}\pm 0.04$	$1.331^{c}\pm 0.1$	1.092 ± 0.3
Average	$0.553^{a}\pm 0.01$	$0.474^{b}\pm 0.02$	$0.323^{b}\pm 0.01$	$0.282^{a}\pm 0.002$	$0.0197^{b}\pm 0.001$	$0.0158^{b}\pm 0.001$	$1.888^{a}\pm 0.09$	$1.612^{b}\pm 0.06$	$1.283^{c}\pm 0.08$
CD	---	0.19	---	---	---	---	0.5	0.3	---
LevelofSignificance	NS	**	NS	NS	NS	NS	*	*	NS

**-Significantat1%level*-Significantat5%levelNS-NonSignificant a,b,c… mean with different superscript in a column differ significantly

IV. CONCLUSION

The study concludes that concentrations of arsenic, lead, cadmium, and mercury in urban sectors are approaching the Maximum Residue Limits (MRL) set by WHO (1998) and EU (2020). This elevation is likely driven by urban industrialization and subsequent environmental pollution. In contrast, levels in semi-urban and rural areas remain comfortably below WHO, EU, and BIS (2012) standards, likely due to the absence of significant groundwater contaminants in these zones.

Because heavy metals can bio accumulate and impact both animal and human health, continuous monitoring of water sources is essential to ensure long-term regional safety and public health.

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