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From Pasture to Plate-Heavy Metal Contamination in Zimbabwean Bovine, Ecosystems, and the Consequences for Public Health: A Scoping Review

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Abstract

Background: Anthropogenic pressures from industrialisation, urbanisation, mining, and intensive agriculture have driven widespread heavy metal enrichment of aquatic sediments. Sediments act as persistent geochemical reservoirs for Lead (Pb), Cadmium (Cd), Arsenic (As), Mercury (Hg), Nickel (Ni), Chromium (Cr), Zinc (Zn), and Copper (Cu) accumulating via atmospheric deposition, effluent inputs, and lithogenic weathering, and functioning as secondary contaminant sources when disturbed by hydrodynamic events, dredging, or redox shifts. This dual role of long-term sink and episodic source underpins chronic ecological exposure, trophic transfer, and extended human health risk.
Methods: The scoping review followed a six-stage framework, namely; question formulation, systematic searching, study selection, data charting, synthesis, and stakeholder consultation. It targeted environmental matrices, bovine tissues, and human health outcomes, with an emphasis on heavy metals and a Zimbabwean focus. The authors identified full papers that were published in the English language over the last twenty (20) years. Searches covered Web of Science, Scopus, PubMed, Google Scholar, regional repositories, and Grey literature using Boolean keywords and reference mining. Records underwent dual independent title/abstract and full-text screening to deduplicate them. Data were also extracted into a standardised charting form and verified by a second reviewer. Findings were synthesised descriptively and thematically. Comparative tabulations were produced where feasible methodological quality was appraised with an adapted checklist, and results were validated through consultation with regional environmental health and veterinary stakeholders. **Findings:** Spatial patterns varied with land use and regulatory capacity: hotspots frequently occurred near mines, smelters, tanneries, informal e-waste sites, industrial zones, and urban runoff corridors. Sediment-bound metals bioaccumulated through aquatic food webs and terrestrial transfer pathways, contaminating forage and irrigation waters and elevating metal burdens in grazing livestock. Bovine tissues, especially liver and kidney, commonly showed the highest accumulation and sometimes exceeded international food-safety limits in affected areas, creating a direct dietary exposure route for humans. Human health implications included nephrotoxicity, neurotoxicity, endocrine

disruption, reproductive impairment, and increased risk of chronic diseases associated with chronic low-dose metal exposure; vulnerable groups included children and populations that relied heavily on contaminated animal products and local water resources.
Conclusion: In Zimbabwe, artisanal gold mining, industrial effluents, agricultural runoff, and urban waste contribute to localised sediment contamination with mercury, lead, cadmium, and arsenic, raising concerns for ecosystem integrity, livestock safety, and public health. Continued monitoring, source control, and integrated risk assessments linking sediments, livestock tissues, and human disease patterns are essential to prioritise interventions and protect community health.

Key Words: *Bioaccumulation, Bovine tissues, Heavy metals, Human health, Sediments, Zimbabwe*

Introduction

Heavy metal contamination in the environment and food chain has emerged as a critical public health concern worldwide, with increasing evidence highlighting its implications for human health (Angon *et al.,* 2024). At the international level, research over recent years has documented a rise in heavy metal pollution due to rapid industrialisation, urbanisation, and environmental degradation (Shifaw, 2018). Chen and Costa (2019) postulate that metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are persistent, bioaccumulative, and often pose serious health risks when they enter the food chain through contaminated soil, water, and air. Certain plant species can absorb heavy metals within their tissues, heightening the risk of contamination of the food chain. Consumption of these contaminated plants by ruminants can therefore lead to deposition of toxic metals in the meat, tissues, and organs of the ruminants (Vanisree *et al.,* 2022). Meat from animals raised on pastures near mining areas has been reported to contain higher levels of heavy metals due to natural activity (Halagarda & Wójciak, 2022).

Regionally, within Africa and neighbouring regions, research has revealed widespread heavy metal pollution stemming from artisanal and industrial activities, agricultural practices, and environmental factors such as mining and waste disposal (Nyika & Dinka, 2023). These activities contribute to elevated levels of heavy metals in sediments, foliage, and livestock tissues, further complicating food safety and public health (Sarker *et al.,* 2022). Countries in the Southern African Development Community (SADC) are increasingly recognising the need for monitoring and regulation, yet data on contamination sources and bioaccumulation in local food supplies remain limited (Selwe *et al.,* 2022).

This review aims to synthesise current findings on heavy metal contamination in foliage, sediments, and bovine meat across multiple levels from international to Zimbabwean contexts and evaluate their impact on human health. Insights from recent scientific literature will help illuminate exposure pathways, health risks, and strategies for reducing contamination, thereby contributing to more effective public health interventions and environmental policies tailored to the needs of vulnerable populations.

Methods

Scoping Framework

The review followed a six-stage scoping methodology: (1) identify research question; (2) identify relevant studies; (3) select studies; (4) chart data; (5) collate, summarise, and report results, and (6) consult stakeholders for contextual relevance. Eligibility criteria included environmental matrices (sediments, foliage), bovine tissues (kidney, liver, muscle, blood) and human health outcomes with emphasis on male-specific disease patterns. The concept covered heavy metals (Pb, Cd, As, Hg, Ni, Cr, Zn, Cu, Mn) focusing on occurrence, distribution, pathways, bioaccumulation and health impacts. Context was global with a sub-focus on Zimbabwe and Southern Africa, accepting all study designs (observational, monitoring, reviews, risk assessments), and restricted to English-language studies published in the past twenty years. However, research permitted older seminal works especially those directly relevant. Information sources comprised Web of Science, Scopus, PubMed, Google Scholar and regional repositories and Grey literature (government reports, NGO assessments, theses, conference proceedings). Searches combined keywords and Boolean operators (e.g., “heavy metal” AND “sediment” OR “bovine” OR “livestock” OR “liver” OR “kidney” AND “Zimbabwe” OR “Southern Africa” AND “human health” OR “male” OR “men”).Reference lists of the included papers and reviews were hand-searched to identify additional records.

Eligibility Criteria

Records were imported into a reference manager, deduplicated, and screened by two independent reviewers at the title/abstract and full-text stages, with disagreements resolved by consensus or a third reviewer. A standardised data-charting form captured bibliographic details, location, matrix sampled, metals analysed, sampling and analytical methods, concentrations, quality-control measures, bioaccumulation findings, exposure pathways, reported health outcomes, including male-specific results, and study limitations. During the process, one reviewer extracted data, and a second verified the entries. Evidence synthesis combined descriptive numerical summaries and thematic analysis (occurrence, sources, pathways, bioaccumulation, health effects, risk assessments), with comparative tabulation by region, matrix, and metal where possible, and narrative integration of human health implications and links to male disease patterns. Methodological quality and reporting completeness were appraised using an adapted checklist for environmental monitoring and observational studies to identify gaps, inconsistencies, and research priorities. Findings were then reviewed with regional environmental health, veterinary, and public-health stakeholders to validate relevance and inform policy and targeted monitoring.

Results

Global Context

Globally, heavy metal contamination in sediments is recognised as a pervasive environmental issue resulting from a multitude of anthropogenic sources. The persistence, toxicity, and bioaccumulative nature of metals such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), and nickel (Ni) have prompted extensive research. Recent studies underscore increasing concentrations of these metals in sediments linked to industrialisation, urbanisation, and mining activities, with significant variations across regions (Birgül, 2024). For example, industrial discharges from steel production, coal combustion, and waste disposal have led to elevated sediment metal levels in water bodies worldwide, particularly in developing countries with weak environmental regulations (Li *et al.,* 2019). Research highlights that sediments act as both sinks and sources of heavy metals; they can accumulate metals over time and subsequently release them into overlying water phases, thus posing long-term ecological and health risks (Sharkawy *et al, 2025*). The process of contamination in sediments is complex, involving multiple pathways including atmospheric deposition, effluent discharges, and natural weathering of rocks (Akhtar, 2021). Furthermore, sediments act as reservoirs for toxic metals, which can be released during environmental disturbances, such as floods and dredging activities, thereby enhancing exposure pathways.

Heavy metals are intrinsically persistent and bioaccumulate, posing substantial risks to both human health and ecological sustainability. According to Roy *et al.* (2022*),* a comprehensive review of recent global data reveals that urban road dust serves as a significant reservoir for heavy metal contamination across diverse geographical regions. Their study systematically examined the ecotoxicological and human health risks associated with heavy metals reported in road dust samples from cities spanning Asia, Europe, Africa, the Americas, and Australia.

Roy *et al.* (2022) compared and synthesised findings from various studies concerning sampling methodologies, extraction procedures, and analytical techniques used to quantify heavy metals, alongside assessments of contamination levels and associated risks. The research identified elevated concentrations of key metals such as lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), manganese (Mn), and iron (Fe), which exceeded natural background soil levels. The degree of contamination showed significant variability across different cities, countries, continents, and over time, largely reflecting diverse anthropogenic activities and historical land use. The study highlighted that Pb and Cd concentrations in road dust remained notably high, primarily attributed to residual leaded gasoline emissions and the prevalence of older vehicle fleets. Among the regions analysed, Europe exhibited the highest zinc contamination levels, followed by Asia, Africa, Australia, and the Americas (North and South America). Copper contamination and the pollution load index (PLI) were highest in European urban areas, with African cities demonstrating the lowest values, while North and South American cities displayed intermediate levels. Ecological risk assessments indicated that Asia faced the highest potential risks posed by heavy metal contamination, with Europe, Australia, the Americas, and Africa following in descending order. A comparison of non-carcinogenic risks for children revealed that Australia was the most vulnerable, due to higher exposure levels to heavy metals in road dust. Asia also showed elevated risks for children, whereas European, African, and American cities demonstrated comparatively lower non-carcinogenic risks for this age group. Importantly, no significant non-carcinogenic health risks were identified for adults across the examined regions. Moreover, carcinogenic risk evaluations indicated that all regions and age groups were within acceptable threshold limits, suggesting a low overall carcinogenic threat on a global scale. This synthesis underscores the urgent need for continued monitoring and targeted mitigation strategies to address the problem of heavy metal pollution in urban environments worldwide, as emphasised by Roy *et al.* (2022).

Continental and Regional Dimensions

Across Africa and the broader continent, heavy metal pollution in sediments is increasingly observed in both urban and rural settings. In Nigeria and South Africa, studies have reported high levels of Pb, Cd, and Cr in sediments proximal to mining sites and industrial discharges, with implications for ecosystem health and human exposure through bioaccumulation (Chris *et al,* 2022). Agricultural runoff containing pesticides and fertilizers adds to sediment contamination, which subsequently impacts aquatic biodiversity and local livelihoods.

Sub-Regional and National Perspectives

Sub-regional studies highlight clear contamination patterns. In Southern Africa, heavy metal hotspots correlate with industrial and mining operations, with livestock near smelters exhibiting liver and kidney cadmium levels above international food safety standards. In West Africa, informal e-waste recycling sites in Ghana, such as Agbogbloshie, release high levels of Pb and Hg into nearby soils and sediments, which subsequently affect grazing cattle. In East Africa, leather tanneries and textile industries in Kenya and Uganda release effluents rich in chromium and lead into local rivers, contaminating sediments and irrigated pasturelands (Alloyway, 2013).

In Nigeria, abattoir studies in Lagos and Port Harcourt have linked elevated Pb and Cd levels in bovine organs to cattle raised near roads, informal dumpsites, and oil-exploration sites. In Kenya, according to Akele *et al.* (2022), sediments in the Nairobi River Basin and in irrigation channels near Thika's tannery industries exhibit detectable levels of Cr and Pb, which have been traced to bovine liver and kidney samples. Those samples' contamination levels exceed the FAO/WHO limits (Akele *et al.,* 2022). District-level exposure often arises from local irrigation with untreated wastewater, grazing on roadside vegetation, and from feeding cattle with crop residues from contaminated fields. These localised contamination patterns are critical because they directly determine the bioaccumulation burden in bovine tissues and the dietary risk for human populations (Halagarda & Wójciak, 2022).

At the national level, Zimbabwe exemplifies the increasing concern over sediment contamination driven largely by artisanal gold mining, industrial activities, agricultural runoff, and urban waste disposal. Recent investigations into sediment quality in Zimbabwe have revealed high concentrations of heavy metals such as Pb, Hg, As, and Cd, especially in mining hotspots. Artisanal mining, particularly gold panning, releases significant amounts of mercury into water bodies, which binds with sediments, thus creating a persistent source of pollution (Dube, 2024; Siziba *et al.,* 2021).

Discussion

Bioaccumulation and Biomagnification Processes

The toxicological significance of heavy metal contamination lies not only in environmental presence but also in the processes of bioaccumulation and biomagnification, which determine the eventual human health risk. Bioaccumulation refers to the progressive buildup of metals in biological tissues, often exceeding environmental concentrations due to the metals' non-biodegradable nature. Plants accumulate metals via root absorption from contaminated soils and sediments and leaf surface deposition of airborne particles. Foliage contamination is particularly critical in livestock production, as cattle grazing on metal-laden pastures ingest these metals directly, initiating the transfer up the food chain.

Heavy metals such as mercury, lead, cadmium, and arsenic are naturally occurring elements that can become toxic when accumulated in living organisms (Annar, 2022). These elements often enter the environment through industrial activities, mining, agricultural runoff, and waste disposal. Once in the environment, heavy metals can enter the food chain, leading to bioaccumulation and biomagnification. Understanding these processes is thus vital because they pose significant health risks to humans and the ecosystem (Ali & Khan, 2019).

The processes of bioaccumulation and biomagnification play critical roles in the transfer of heavy metals from sediments into living organisms and ultimately humans. Bioaccumulation occurs when organisms absorb metals from their environment. Such metals can be found in sediments, water, or food, and if ingested can be stored in animal tissues such as gills, liver, and muscles. For instance, benthic invertebrates and fish can accumulate high concentrations of metals like mercury and cadmium from contaminated sediments. These metals tend to biomagnify up the food chain, leading to higher concentrations in predatory species consumed by humans (Nnaji *et al.,* 2023; Oros, 2025).

Bioaccumulation refers to the build-up of substances, such as heavy metals, in the tissues of an organism over time (Nnaji *et al.,* 2023). This process occurs when an organism absorbs contaminants faster than it can eliminate them. For example, fish living in contaminated water can accumulate mercury in their tissues. In lakes contaminated by industrial waste, freshwater fish like trout, or catfish can accumulate mercury to levels that are dangerous for human consumption (Malik *et al.,* 2020). The mercury enters the fish mainly through absorption from water and food. Biomagnification occurs when the concentration of a substance increases as it moves up the food chain; predators consume prey that has already accumulated heavy metals, leading to higher concentrations in larger, top predators (Ali & Khan*,* 2019). One well-documented case illustrating the dangers of biomagnification is the presence of mercury in fish and its subsequent impact on human health. Methylmercury, a highly potent neurotoxin, bioaccumulates in aquatic organisms and poses significant health risks to humans (Novo *et al.,* 2021).

Bovine

The presence of heavy metals in bovine tissues is a pressing concern for food safety and human health. As cattle are exposed to heavy metals through feed, water, and environmental pollution, the consumed toxic substances accumulate in their tissues, potentially causing harm to humans who consume them later (Akele *et al.,* 2022).

Heavy metal contamination in bovine meat, particularly in organs such as kidneys, liver, and muscles, poses significant health risks to humans due to toxicity, bioaccumulation, and biomagnification in the food chain. Recent studies have highlighted the prevalence of heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As), in cattle tissues, often exceeding maximum residual limits (MRLs) (Akele, *2022;* Tchounwou *et al.,* 2012).

Additionally, the presence of heavy metals in livestock poses a significant threat to food safety and public health. Heavy metals such as lead and cadmium can accumulate in animal tissues and be transferred to humans through the consumption of contaminated meat and organs. A recent study in Al-Ahsa, Saudi Arabia, found that the liver and kidneys of cattle had higher levels of aflatoxins, lead, and cadmium, highlighting the need for regular monitoring and strict regulations to minimise the risks associated with heavy metal contamination in livestock (Al-Sultan *et al.,* 2022).

Animal kidneys are the biggest reservoir of heavy metals. Kidneys tend to accumulate higher levels of heavy metals, particularly Cd, compared to the muscles and liver (Akan *et al.,* 2010). It has also been established that areas with increasing anthropogenic activities such as mining and farming are a source of contamination for heavy metals. Industrial pollution, agricultural practices, contaminated feed and water, and proximity to mining sites contribute to heavy metal contamination in cattle (Aljerf, 2018). It is also important to note that heavy contamination varies from one area to another. Heavy metal concentrations also vary depending on location, with areas nearer mining sites or industrial zones showing higher levels of contamination than those further away (Dermauw *et al.,* 2014*)*.

Gwani and Tyokumbur (2019) assert that heavy metal contamination in cattle is a significant public health concern in Nigeria. In their study, "Appraisal of Heavy Metals (Lead and Cadmium) in the Muscle and Internal Organs of Cattle Slaughtered in Ibadan," the authors investigated the levels of lead (Pb) and cadmium (Cd) in various parts of cattle slaughtered in Ibadan, Nigeria. Their study revealed that the concentration levels of Pb and Cd in the muscle and internal organs of cattle exceeded the World Health Organization's (WHO) permissible limits. The authors specifically found that the Pb concentration in muscle tissue ranged from 0.00 to 0.81 ppm, while Cd concentration in kidney tissue ranged from 0.40 to 7.65 ppm (Gwani & Tyokumbur, 2019). Their findings suggest that the consumption of contaminated cattle meat and organs could pose a significant health risk to humans.

The findings from Gwani and Tyokumbur's (2019) study have significant implications for public health policy and practice in Nigeria. They noted that the levels of cadmium and lead in cow meat called for continuous monitoring of the environment to ensure it was protected from further pollution (Gwani and Tyokumbur, 2019). Therefore, according to Gwani and Tyokumbur (2019), policymakers and public health officials should take proactive measures to address the issue of heavy metal contamination in cattle as well as protect the health and well-being of consumers.

A study done by Deventer (2018) in South Africa found that heavy metal contamination in bovine meat was a significant public health concern in the country. In the study entitled "Mycotoxin prevalence and heavy metal contamination of South African red meat" Van Deventer investigated the effect of selected environmental factors on meat contamination. The study's findings are crucial in understanding the current trends and implications of heavy metal contamination in bovine meat.

Deventer's (2018) study showed that in 2012, two samples had tested positive for heavy metals namely; lead (610 μg/kg) in Malmesbury, and mercury (200 μg/kg) in Bela-Bela. These findings suggest that heavy metal contamination is a significant concern for South Africa's red meat. The study also found that there was no correlation between heavy metal contamination levels and environmental factors such as weather conditions. This suggests that other factors such as agricultural practices, feed quality, and industrial pollution, may be contributing to heavy metal contamination in bovine meat. Deventers (2018) study thus emphasises the need for urgent attention to the issue of heavy metal contamination in bovine meat. The findings suggest that further research is needed to understand the sources of contamination and develop effective control strategies. By understanding the trends and implications of heavy metal contamination in bovine meat, nations can take steps to protect public health and ensure food safety.

Health Impact of Heavy Metal Exposure

Heavy metal exposure through contaminated food sources poses significant health risks. These metals accumulate in the body and can cause long-term damage even at low levels of exposure. Heavy metals like lead, cadmium, mercury, arsenic, and chromium affect various organ systems. Lead primarily targets the nervous system, blood, and kidneys, causing cognitive decline, hypertension, and anemia. Cadmium accumulates in the kidneys and bones, leading to renal damage and skeletal demineralisation (Okoye, 2011). Mercury is neurotoxic and can cause cognitive impairment, while arsenic interferes with cellular respiration and increases cancer risk. Hexavalent chromium is a genotoxin that can cause immunosuppression and cancer.

Men are particularly vulnerable to heavy metal exposure due to occupational and biological factors. Many men work in industries with high exposure risks, and their reproductive systems are sensitive to metal-induced damage. Lead and cadmium can impair sperm quality, while mercury can disrupt testosterone production. Heavy metals also act as endocrine disruptors, causing hormonal imbalances that affect fertility and reproductive health. Long-term exposure to heavy metals increases the risk of cancer, kidney dysfunction, and neurological complications (Muposhi, 2015). Cadmium and arsenic are classified as Group 1 carcinogens, and exposure to these metals can cause prostate and testicular cancers. The pathophysiological mechanisms involve oxidative stress, endocrine disruption, and epigenetic modification, leading to cumulative and often irreversible damage (Okoye, 2011).

Studies have shown strong associations between heavy metal exposure and adverse health effects in men. In Nigeria, Kenya, China, and India, higher levels of heavy metals in food sources have been linked to reduced sperm quality, increased cancer risk, and kidney dysfunction. These findings highlight the need for integrated surveillance and regulatory measures in order to protect vulnerable populations. The health impacts of heavy metal exposure are significant and far-reaching. Understanding these risks is crucial for developing effective strategies to mitigate exposure and protect public health. By addressing the prevalence of heavy metal contamination in food sources, countries can reduce the risk of adverse health effects and promote overall well-being among the population (Sutton, 2012).

This body of evidence reveals a clear chain of risk connecting environmental contamination and bovine bioaccumulation with male-specific health outcomes. The cumulative effects of reproductive impairment, hormonal disruption, neurotoxicity, and cancer risk highlight the urgent need for integrated surveillance and regulatory measures to protect vulnerable populations. These impacts are further illuminated by examining the prevailing disease patterns in men linked to heavy metal exposure.

Mitigation Strategies for Reducing Heavy Metal Contamination

Heavy metal contamination in the environment poses significant risks to ecosystems, agriculture, and human health (Alengebawy *et al.,* 2021). To address this issue, various mitigation strategies can be employed across different stages of contamination, including in foliage, sediments, and livestock such as bovine. These strategies encompass sustainable agricultural practices, pollution control measures, and innovative remediation technologies, each playing a vital role in reducing the bioavailability and accumulation of heavy metals (Selvam *et al.,* 2024).

Pollution control measures are essential for reducing heavy metal input at the source. Legal regulations limiting emissions from industries, such as enforcing the use of scrubbers in smokestacks, electrostatic precipitators, or wastewater treatment systems have shown significant success. For example, stricter pollution controls in countries like the United States and the European Union have led to substantial reductions in atmospheric mercury and lead emissions, decreasing contamination levels in sediments and farmland (Zlati *et al.,* 2022).

Remediation technologies offer targeted solutions for contaminated sites. Techniques such as soil washing, where heavy metals are extracted using chemical solutions, and stabilisation/solidification, which immobilises metals in the soil, are commonly used (Tyagi & Annachhatre, 2023). In sediments, capping contaminated areas with clean sediment or inert materials prevents heavy metals from entering the food chain. Bioremediation using fungi, bacteria, or plants to detoxify or immobilise heavy metals has also proven effective. For instance, fungi capable of bioaccumulating metals have been successfully applied in wetlands to detoxify contaminated sediments (Chugh *et al.,* 2022).

When it comes to livestock, including bovine animals, controlling heavy metals involves managing contaminated feed and water sources and implementing regular monitoring to prevent accumulation in meat tissues. In countries such as Canada, extensive feed monitoring and strict environmental guidelines have effectively minimised heavy metal presence in beef production (Charlebois *et al.,* 2021).

Key Evidence Gaps Identified from the Review

Research on metal contamination from Zimbabwe shows several critical gaps. For instance, geographic coverage is limited and lacks high-resolution, nationwide data, with most works focused on known mining hotspots while rural, peri-urban, and downstream communities remain under-sampled. Temporal data are also sparse, meaning long-term trends, seasonal variability, and responses to remediation or regulation are poorly characterised. Many studies only report total metal concentrations and omit key toxicants or speciation information (for example, organic versus inorganic arsenic or methylmercury) that determines bioavailability and toxicity. Integration across environmental and biological matrices is weak, hindering tracing of exposure pathways and quantification of transfer factors between sediments, foliage, forage, bovine tissues, and human biomarkers. Furthermore, dietary exposure and dose assessments are limited, with few studies combining bovine tissue concentrations and consumption patterns to estimate human intake and risk for vulnerable groups including specific male subpopulations. Another issue is that direct epidemiological links between environmental or bovine metal burdens and human disease incidence or male-specific outcomes (reproductive, endocrine, renal, neurocognitive) are scarce. In addition, methodological heterogeneity and gaps in QA/QC, varying sampling designs, analytical methods, detection limits, and quality control reporting impede comparability and meta-analysis. Longitudinal, cohort, and intervention studies evaluating remediation or policy effectiveness are also largely absent in research from Zimbabwe. One Health and socio-behavioural integration are minimal, with few interdisciplinary studies combining veterinary, human health, ecological, and socioeconomic data to contextualise exposure drivers and mitigation feasibility. Finally, research on policy, governance, food-safety enforcement, public awareness, and community-level risk communication remains underdeveloped.

Conclusion

Sediment-bound heavy metals are a persistent, widespread hazard that bioaccumulate in forage and bovine tissues, particularly in the liver or the kidney, thus creating direct dietary exposure routes for people. In Zimbabwe, contamination hotspots tied to mining, industry, urban runoff, and informal waste are documented, but studies are fragmented, spatially and temporally limited, and methodologically inconsistent, with crucial gaps in metal speciation, multi-matrix linkages, and epidemiological evidence for male-specific health outcomes. Closing these gaps requires coordinated One Health monitoring, standardised QA/QC, longitudinal biomonitoring, and exposure–dose assessments that incorporate local diet and interdisciplinary studies linking bovine tissue burdens to human biomarkers. Priority actions are targeted surveillance in high-risk zones, laboratory capacity strengthening, research-to-policy translation, and community-level risk mitigation to move from mapping contamination toward evidence-based interventions that protect ecosystems, livestock, and public health.

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