Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 1 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Heavy Metal Accumulation And Spatial Variation In Domestic Chicken Tissues Across Industrial, Urban, And Rural Areas Of Nowshera, Khyber Pakhtunkhwa, Pakistan

Usman Gul
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; ug436818@gmail.com
Muhammad Fawad Khan
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; fawad62005@gmail.com
Adnan Khan
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; imrankhan2014923@gmail.com
Fatima Shaheen
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; anmoolfatima39@gmail.com
Naima Gul
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; Dadfairy1122@gmail.com
Hira Begum
Department of Zoology, Government Postgraduate College Nowshera, Khyber Pakhtunkhwa, Pakistan Email; waseembahadar299@gmail.com
Ahmad Suleman Sohail
Department of Zoology, Kohat University of Science and Technology, Khyber Pakhtunkhwa, Pakistan Email; sulemansuhail@gmail.com
Javed Khan
Department of Zoology, Abdul Wali Khan University Mardan**,** Khyber Pakhtunkhwa, Pakistan Email; javedkhanbio71@gmail.com
Abbas Khan
Department of Zoology, Abdul Wali Khan University Mardan**,** Khyber Pakhtunkhwa, Pakistan Email; abbas.khan884official@gmail.com
Zahid Gul (Corresponding Author)
Department of Zoology, University of Peshawar, Khyber Pakhtunkhwa, Pakistan
Email; zahidgul02@uop.edu.pk

ABSTRACT

Heavy metal contamination of food products is an important environmental and public health concern because persistent metals can accumulate in edible tissues and enter the human food chain. This study evaluated the concentrations of cadmium (Cd), lead (Pb), and nickel (Ni) in the thigh muscle, liver, and gizzard of locally raised domestic chickens collected from rural, urban, and industrial habitats in Pabbi, Nowshera, and Jehangira, District Nowshera, Khyber Pakhtunkhwa, Pakistan. Nine locally raised domestic chickens were sampled, with one chicken collected from each

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habitat (rural, urban, and industrial) within each of the three selected tehsils. In addition, one commercially reared broiler chicken was included as a reference sample. Approximately 1 g of each tissue (thigh muscle, liver, and gizzard) was collected, subjected to acid digestion, and diluted to a final volume of 50 mL before analysis. The concentrations of cadmium (Cd), lead (Pb), and nickel (Ni) were determined using atomic absorption spectrophotometry. Because the three tissue samples were obtained from the same individual chickens and the number of independent chickens was limited, non-parametric statistical tests were used to assess differences among tissues and habitats. The Friedman test showed a significant difference in Cd concentration among tissues ($\chi^2 = 7.26$, $p = 0.027$), whereas differences in Pb ($p = 0.169$) and Ni ($p = 0.459$) were not significant. Habitat-related differences were significant for Cd in the gizzard ($H = 6.87$, $p = 0.032$) and Ni in the liver ($H = 6.44$, $p = 0.039$). Several individual tissue samples contained metal concentrations exceeding the reference limits reported in the study, including Pb (7.50 mg/kg) in muscle and Cd (4.70 mg/kg) in liver. In the broiler reference chicken, Cd was detected in the liver and gizzard, whereas Pb and Ni were below the reported detection limit. Overall, the findings demonstrate spatial and tissue-specific variation in heavy metal accumulation in locally raised domestic chickens and highlight the potential food-safety implications of environmental metal exposure in the study area. Larger studies with increased sample sizes and assessment of environmental exposure pathways are recommended to better characterize contamination levels and associated health risks.

Keywords: Public Health, Thigh Muscle, Edible Tissues, Spectrophotometry, Friedman Test, Food-Safety

Introduction

Heavy metals comprise a group of naturally occurring elements characterized by relatively high atomic mass and density, several of which are toxic to living organisms even at low concentrations (Fan et al., 2026). Environmentally important metals and metalloids include lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), nickel (Ni), and zinc (Zn). Although some metals, such as zinc and nickel, are essential micronutrients at appropriate concentrations, excessive exposure can adversely affect biological systems (Engwa et al., 2019). In the twenty-first century, contamination by toxic metals has become an important environmental and public health concern because these elements are persistent, non-biodegradable, and capable of accumulating in organisms and moving through food webs. Their persistence allows them to remain in soils, sediments, water, and biological tissues for prolonged periods, increasing the potential for chronic exposure in wildlife, livestock, and humans (Ali & Khan, 2019).

Heavy metals enter the environment through both natural and anthropogenic processes. Natural sources include rock weathering, volcanic activity, erosion, and the geochemical mobilization of elements from parent materials. However, anthropogenic activities such as industrialization, mining, metal processing, battery recycling, fossil-fuel combustion, agricultural practices, vehicular emissions, and the disposal of untreated municipal and industrial wastes have substantially increased metal concentrations in many environments (Kumar et al., 2020). Once released, heavy

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metals can circulate among soil, water, plants, and animals. Their uptake by organisms results in bioaccumulation, while their progressive concentration through successive trophic levels may lead to bio-magnification (Ali & Khan, 2019). At the cellular level, heavy metals can bind to proteins and sulfhydryl groups, disrupt essential enzymatic processes, promote the generation of reactive oxygen species (ROS), induce oxidative stress, and damage cellular membranes and DNA. Prolonged exposure may consequently affect the nervous, renal, hepatic, respiratory, reproductive, and immune systems and may contribute to carcinogenic effects (Engwa et al., 2019).

Among environmentally important contaminants, Pb, Cd, and Ni are of particular concern because of their persistence and potential transfer into food-producing animals. Lead contamination is commonly associated with industrial emissions, metal processing, battery recycling, vehicular sources, and contaminated waste, and exposure can produce neurological, hematological, renal, and developmental effects (Balali-Mood et al., 2021). Cadmium may enter agricultural ecosystems through industrial discharges, mining activities, sewage, and phosphate fertilizers and can subsequently accumulate in crops and other components of the terrestrial food chain (Nordberg et al., 2015). Nickel is released from metallurgical industries, fossil-fuel combustion, waste materials, and other industrial activities and may cause respiratory, dermatological, and systemic effects following excessive exposure (ATSDR, 2020). Because these contaminants can persist in environmental matrices and enter agricultural food chains, monitoring their concentrations in livestock and poultry is important for evaluating environmental contamination and potential food-safety risks.

Domestic chickens are particularly useful biological indicators of localized environmental contamination because free-ranging birds frequently forage over a relatively small area and may ingest soil, vegetation, insects, household refuse, contaminated feed, and other environmental materials. Consequently, the concentration of heavy metals in their tissues can provide an indication of local exposure and environmental availability. Tissue-specific analysis is also important because metals are not distributed uniformly throughout the body. Organs involved in metabolism, detoxification, and storage, particularly the liver and gizzard, may retain greater concentrations of certain contaminants than skeletal muscle (Korish & Attia, 2020). Assessment of edible muscle tissue is especially relevant from a food-safety perspective, whereas analysis of internal organs provides additional information about the biological accumulation and distribution of metals within exposed birds.

Nowshera District of Khyber Pakhtunkhwa (KP), Pakistan, represents an appropriate area for investigating spatial variation in heavy-metal exposure because it contains industrial, urban, peri-urban, and rural agricultural environments. Tehsils including Nowshera, Pabbi, and Jehangira differ in land use, human activity, agricultural practices, waste generation, traffic density, and proximity to industrial and other potential pollution sources. Such environmental heterogeneity may produce differences in the availability and transfer of heavy metals to free-ranging poultry. Comparing domestic chickens originating from industrial, urban, and rural environments can therefore provide useful evidence of spatial differences in contaminant exposure. Inclusion of commercially reared broiler chickens as a reference group further provides a basis for distinguishing environmental exposure in

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scavenging domestic birds from background concentrations associated with controlled poultry production.

Therefore, the present study was designed to investigate the concentrations of selected heavy metals, particularly Pb, Cd, and Ni, in the gizzard, liver, and skeletal muscle tissues of domestic chickens collected from industrial, urban, and rural areas of Nowshera District (KP), Pakistan. The study also aimed to evaluate spatial variation in metal accumulation and compare free-ranging domestic chickens with commercially reared broilers. The findings are expected to provide baseline information on tissue-specific heavy-metal accumulation and contribute to the assessment of environmental contamination and potential food-safety risks associated with poultry consumption in the region.

Materials and Methods

Study area and sampling design

This study was conducted in three tehsils, namely Jahangira, Pabbi, and Nowshera, of Nowshera District, Khyber Pakhtunkhwa (KP), Pakistan. The study area encompasses diverse land-use patterns, including rural agricultural areas, urban settlements, and industrial zones, which may differ in their potential exposure to environmental contaminants. A stratified sampling design was employed to obtain domestic chickens from three habitat types (rural, industrial, and urban) within each selected tehsil. One domestic chicken was collected from each habitat in each tehsil, resulting in a total of nine domestic chickens. In addition, one commercially reared broiler chicken was included as a reference specimen to provide a comparative baseline for heavy-metal concentrations under controlled commercial rearing conditions. Thus, a total of ten chickens were included in the study.

Inclusion criteria

Locally reared domestic chickens were included in the study based on predefined selection criteria. All selected domestic chickens were female to minimize potential sex-related variation in heavy-metal accumulation. The birds were more than 10 months of age to ensure physiological maturity and adequate duration of exposure to environmental contaminants. Only chickens that had been continuously reared within the respective sampling areas and had not been brought from outside the study district were included.

Exclusion criteria

Domestic chickens that were not locally reared within the selected sampling areas were excluded from the study. Birds purchased or introduced by farmers from outside Nowshera District were excluded because their previous exposure history and environmental conditions could not be reliably determined. Chickens that did not meet the predefined age or sex criteria were also excluded to maintain consistency among the sampled domestic birds.

Sample Collection and Preparation

A total of 10 chickens, comprising nine locally reared domestic chickens and one commercially reared broiler, were included in the study. The domestic chickens were

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female and more than 10 months of age, whereas the commercially reared broiler was included as a reference specimen. The domestic chickens weighed approximately 1.5 kg and had sufficient exposure time to the environmental conditions of their respective habitats. The broiler chicken was obtained directly from a commercial poultry farm operating within the selected study region and had been maintained under controlled commercial farming conditions (Jadoon et al., 2026).

The selected birds were humanely euthanized and adequately bled before tissue collection to minimize residual blood in the tissues, which could potentially influence the measured concentrations of heavy metals. Following slaughter, samples of the liver, gizzard, and leg skeletal muscle were collected using hygienic procedures. Each tissue sample was carefully handled to minimize external contamination during collection and processing. The collected tissues were rinsed thoroughly with distilled water to remove adhering blood, debris, and other surface contaminants. The samples were subsequently blotted dry using clean absorbent paper. Approximately 1 g of each tissue sample was accurately weighed using a digital analytical balance and transferred into separately labelled, clean conical flasks for subsequent digestion and analysis (Hossain et al., 2023).

A wet-acid digestion procedure was employed for the complete breakdown and dissolution of the tissue samples prior to instrumental analysis (Kia et al., 2024). Appropriate precautions were taken during digestion to minimize contamination and loss of analytes. Following digestion, the prepared samples were appropriately labelled and transported to the Centralized Resource Laboratory (CRL), University of Peshawar, for determination of heavy-metal concentrations using atomic absorption spectrophotometry (AAS).

Heavy Metal Detection

The concentrations of lead (Pb), cadmium (Cd), and nickel (Ni) were determined in the liver, gizzard, and skeletal muscle samples using atomic absorption spectrophotometry (AAS). The digested tissue samples were analyzed under appropriate instrumental conditions for each target metal. The concentrations obtained from the instrument were recorded for each tissue and sampling location and subsequently used to evaluate differences in heavy-metal accumulation among the sampled habitats and chicken groups. The analysis of multiple tissues also enabled assessment of tissue-specific variation in the accumulation of Pb, Cd, and Ni.

Statistical Analysis

The data obtained from the analysis of Pb, Cd, and Ni concentrations were organized according to habitat, tehsil, chicken group, and tissue type. Descriptive statistical analyses were performed, and the results were expressed as mean ± standard deviation (SD). The data were presented graphically using Microsoft Excel to facilitate comparison of heavy-metal concentrations among rural, industrial, and urban habitats and among the different tissues examined. Because the sample size was limited and the three tissue types were obtained from the same individual chickens, interpretation of the results focused primarily on descriptive patterns and tissue-specific variation.

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http://amresearchreview.com/index.php/Journal/about

Ethical Approval

Ethical approval for the study was obtained from the Ethical Approval Committee of Government Postgraduate College Nowshera, affiliated with Abdul Wali Khan University Mardan, Khyber Pakhtunkhwa, Pakistan. All procedures involving the collection and euthanasia of chickens were conducted in accordance with the ethical requirements and institutional guidelines applicable to animal-based research. The handling and collection of tissue samples were performed with appropriate care to minimize unnecessary distress and ensure responsible use of experimental animals.

Result

3.1 Heavy Metal Concentration Across Industrial, Urban, and Rural Habitats

The concentrations of selected heavy metals (Pb, Cd, and Ni) were determined in domestic chickens collected from industrial, urban, and rural habitats. Lead (Pb) showed the highest concentration in the industrial habitat (5.9 mg/kg), followed by the rural habitat (3.5 mg/kg). In contrast, the highest concentration of cadmium (Cd) was recorded in the urban habitat (4.0 mg/kg) (Table.1). The concentrations of the analyzed heavy metals varied among habitats, indicating spatial differences in environmental exposure. The recorded concentrations of the respective heavy metals exceeded the permissible limits established for edible animal tissues, as presented in Table 2, indicating a potential food-safety concern associated with the consumption of contaminated poultry tissues.

Table 1. Concentrations of Cd, Pb, and Ni (mg/kg) in domestic chickens across the different habitats

Sampling Area	Sample Sites	Organ/Tissue	Cadmium (Cd)	Lead (Pb)	Nickel (Ni)
Industrial area	Nowshera	Liver	3.5	5.9	2
	Nowshera	Gizzard	1	2.85	1.55
	Nowshera	Muscle	0.5	1.5	0.4
	Jehangira	Liver	2.05	2.71	0.4
	Jehangira	Gizzard	1.6	2	6
	Jehangira	Muscle	1.4	3.5	0.3
	Pabbi	Liver	1.05	0.5	2.1
	Pabbi	Gizzard	1.1	5.5	0.9
	Pabbi	Muscle	0.01	2	0.02
Rural Area	Nowshera	Liver	1.15	2.8	3.15
	Nowshera	Gizzard	0.3	1.5	1.07
	Nowshera	Muscle	0.65	3	2.5
	Jehangira	Liver	1	3.2	2.96
	Jehangira	Gizzard	0.01	2.95	1.1
	Jehangira	Muscle	0.07	2.15	0.01
	Pabbi	Liver	0.15	3	3.05

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Online ISSN 3007-3197
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http://amresearchreview.com/index.php/Journal/about

	Pabbi	Gizzard	0.1	0.6	0.55
	Pabbi	Muscle	0.03	3.5	0.65
Urban Area	Nowshera	Liver	1.95	2.2	0.02
	Nowshera	Gizzard	0.5	3.2	2
	Nowshera	Muscle	0.25	3.01	1.5
	Jehangira	Liver	4	3.12	0.12
	Jehangira	Gizzard	1	2.2	2.1
	Jehangira	Muscle	2	2.8	1.9
	Pabbi	Liver	0.9	1.5	1
	Pabbi	Gizzard	0.9	3	3.5
	Pabbi	Muscle	1.15	2.56	0.9

Table 2. Permissible limits of selected heavy metal in chicken Muscle and Edible offal (WHO and FAO**)**

Heavy metal	Muscle/ meat (mg/kg	Edible offal (mg/kg)	Reference
Cadmium	0.05	0.50	Korish & Attia, 2020; Hossain *et al.*, 2023
Lead	0.10	0.50	
Nickel	0.10	0.10	

Tissue-Specific Accumulation of Heavy Metals

The concentrations of heavy metals varied among the examined tissues, with lead (Pb) showing comparatively higher accumulation in the liver, gizzard, and skeletal muscle. The mean concentrations of Pb were **2.77 mg/kg in the liver, 2.64 mg/kg in the gizzard, and 2.67 mg/kg in the muscle,** respectively (Table 3). The liver exhibited the highest mean Pb concentration, followed by muscle and gizzard. This tissue-specific variation suggests differential accumulation and distribution of Pb within the body of domestic chicken.

Table 3. The mean concentration of Cd, Pb and Ni in liver, gizzard and muscle

Tissue	Cd (mg/kg) Mean ± SD	Pb (mg/kg) Mean ± SD	Ni (mg/kg) Mean ± SD
Liver	1.83 ± 1.44	2.77 ± 1.47	1.64 ± 1.29
Gizzard	0.72 ± 0.53	2.64 ± 1.36	2.09 ± 1.71
Muscle	0.67 ± 0.70	2.67 ± 0.68	0.91 ± 0.88

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http://amresearchreview.com/index.php/Journal/about

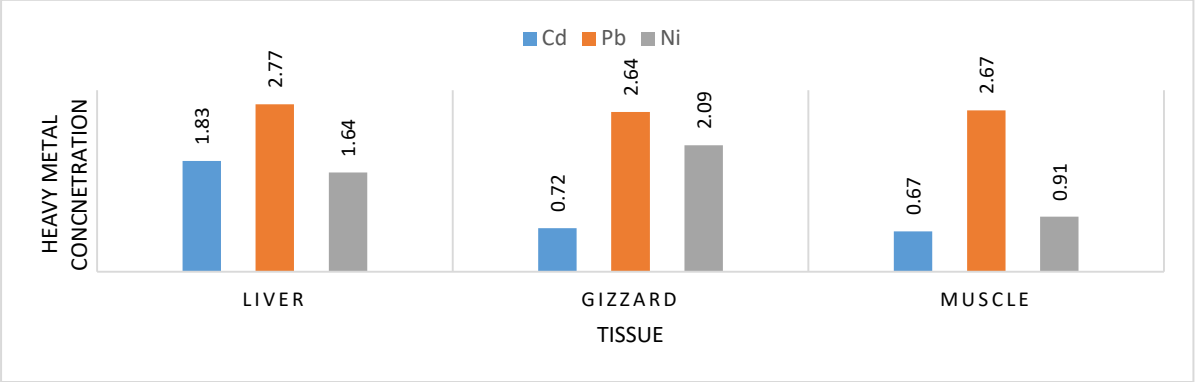

Figure 3.1. Heavy metal concentration in liver, gizzard, muscle

Spatial Variation Among Sampling Sites

The descriptive mean ± SD values of heavy-metal concentrations across the sampling sites representing the three habitats are presented in Table 4. Among the three tehsils, Nowshera recorded the highest mean concentration of Pb (2.88 ± 1.30 mg/kg), followed by Jehangira (2.74 ± 0.52 mg/kg) and Pabbi (2.46 ± 1.56 mg/kg). These results indicate spatial variation in Pb accumulation among the sampling sites. The observed differences may reflect variation in local environmental conditions, land-use patterns, and the potential availability of heavy-metal sources across the three tehsils.

Table 4. Heavy metal concentration across three habitats.

Sampling site	Cd (mg/kg) Mean ± SD	Pb (mg/kg) Mean ± SD	Ni (mg/kg) Mean ± SD
Nowshera	1.09 ± 1.05	2.88 ± 1.30	1.58 ± 0.98
Jehangira	1.54 ± 1.39	2.74 ± 0.52	1.65 ± 1.92
Pabbi	0.60 ± 0.51	2.46 ± 1.56	1.41 ± 1.20

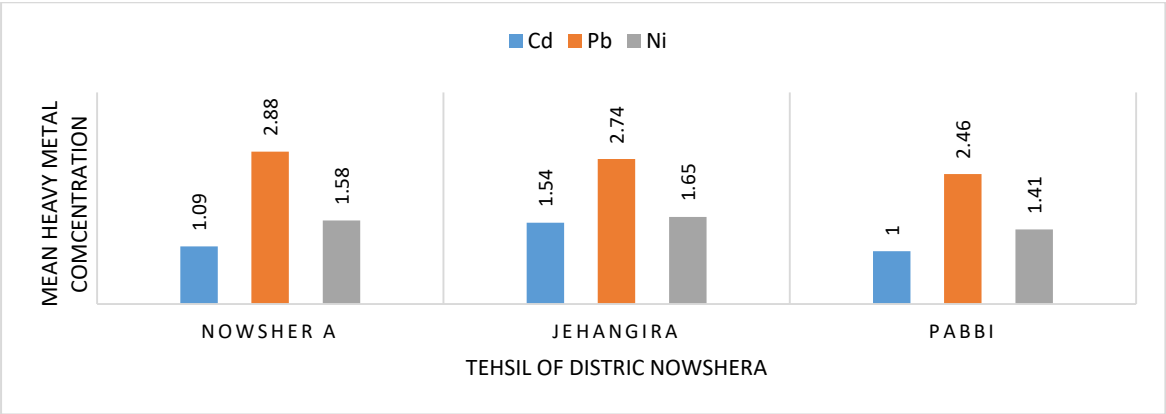

Figure 3.2. Heavy metal concentration in Tehsil of District Nowshera

Comparison with permissible limits

The heavy metal concentration in the domestic chickens were relatively higher as compared to the WHO permissible limits for poultry muscle and edible offal table 5.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 1 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Table 5. Comparison of obtained concentration with permissible limit

Metal	Tissue	Observed mean (mg/kg)	Permissible limit (mg/kg)
Cd	Liver	1.83	0.50
Cd	Gizzard	0.72	0.50
Cd	Muscle	0.67	0.05
Pb	Liver	2.77	0.50
Pb	Gizzard	2.64	0.50
Pb	Muscle	2.67	0.10
Ni	Liver	1.64	0.10
Ni	Gizzard	2.09	0.10
Ni	Muscle	0.91	0.10

heavy metal concentration in Broiler (control) samples

Broiler chickens were reared on controlled commercial feeds, therefore show relatively low level of heavy metals (Table 6). The concentration of nickel was below the limit of detection.

Table 3.6. Shows concentration of heavy metals in tissues of Broiler chicken

Organ	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)
Liver	0.45	0.01	ND (<LOD)
Gizzard	0.7	ND (<LOD)	ND (<LOD)
Muscle	0.06	ND (<LOD)	ND (<LOD)

Note: ND (<LOD) = not detected, below the limit of detection

Discussion

In the present study, the concentrations of cadmium (Cd), lead (Pb), and nickel (Ni) were determined in the liver, gizzard, and skeletal muscle tissues of domestic chickens collected from industrial, urban, and rural areas of Nowshera District, Khyber Pakhtunkhwa, Pakistan. The results demonstrated variation in heavy-metal concentrations among different tissues, sampling sites, and habitat types. Several tissue samples contained metal concentrations that exceeded the permissible limits established for food products, raising potential concerns regarding environmental contamination and food safety. Poultry and poultry-derived products can serve as useful indicators of environmental metal contamination because free-ranging chickens are continuously exposed to contaminated soil, vegetation, insects, water, household waste, and other environmental materials. Heavy metals absorbed from these sources can subsequently accumulate in different tissues and potentially enter the human food chain through consumption of contaminated poultry products (Hossain et al., 2023; Aljohani, 2023).

Cadmium concentrations were particularly elevated in the liver, especially among chickens collected from industrial and urban habitats, whereas comparatively lower concentrations were observed in skeletal muscle. The relatively greater accumulation of Cd in the liver can be attributed to its important role in metabolism, detoxification, and metal sequestration. Cadmium has a strong affinity for metallothionein and other

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http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 1 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

sulfhydryl-containing proteins, which can facilitate its retention and accumulation in hepatic tissues following exposure. Consequently, the liver is frequently considered an important target organ for Cd accumulation in animals. Studies conducted on poultry in different Asian and African regions have similarly reported higher Cd concentrations in liver tissues than in muscle tissues, supporting the tissue-specific pattern observed in the present study (Korish & Attia, 2020; Hossain et al., 2023).

Lead was also detected at relatively high concentrations in several liver, gizzard, and muscle samples. The concentrations recorded in a number of samples exceeded the permissible limits of 0.10 mg/kg for meat and 0.50 mg/kg for edible offal reported by FAO/WHO. The comparatively higher Pb concentrations observed in chickens from industrial and urban habitats may be associated with greater exposure to anthropogenic sources. Potential sources include industrial emissions, vehicular exhaust, contaminated feed ingredients, polluted soil, atmospheric deposition, and improperly disposed waste. Free-ranging chickens can ingest Pb-contaminated soil and dust while foraging, providing a direct pathway for the transfer of environmental Pb into their tissues. Aljohani (2023) reported that environmental Pb contamination remains an important concern in developing countries, where rapid industrialization and urbanization can increase the deposition and persistence of heavy metals in agricultural and residential environments. Therefore, the elevated Pb concentrations observed in the present study may reflect the influence of anthropogenic activities within the study area.

Nickel concentrations demonstrated considerable variation among tissues and sampling sites. In the present study, Ni accumulation was comparatively higher in gizzard tissues, followed by liver and muscle tissues. The relatively greater accumulation in the gizzard may be related to its direct contact with ingested materials, including soil particles, vegetation, insects, and other environmental matter consumed by free-ranging chickens. Important environmental sources of Ni include metallurgical and industrial activities, fossil-fuel combustion, wastewater, contaminated soils, and atmospheric deposition. Previous studies have reported elevated Ni concentrations in poultry tissues collected from or near industrialized environments, indicating that environmental contamination can contribute substantially to metal uptake by poultry (Hossain et al., 2023). The presence of Ni in tissues examined in the current study therefore highlights the importance of continued environmental monitoring in areas where poultry are raised under free-ranging conditions.

Habitat-wise comparison showed that chickens from industrial areas generally exhibited the highest concentrations of the analyzed heavy metals. Industrial activities, improper waste disposal, vehicular movement, combustion processes, and atmospheric emissions may contribute to increase environmental loading of heavy metals in these areas. Relatively elevated concentrations were also observed in chickens from urban habitats, which may be associated with municipal waste generation, pesticide and insecticide use, vehicular emissions, construction activities, and other anthropogenic sources. Although rural environments are generally expected to have comparatively lower levels of industrial contamination, the present study also detected considerable concentrations of Cd, Pb, and Ni in some chickens from rural habitats. Agricultural activities, contaminated irrigation water, agricultural inputs,

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http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 1 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

contaminated feed, and atmospheric transport of pollutants may contribute to metal exposure even in relatively less industrialized areas (Aljohani, 2023).

The present findings further demonstrated clear tissue-specific differences in heavy-metal distribution. The liver showed relatively greater accumulation of Cd and Ni than skeletal muscle, which is consistent with the established role of the liver in metal metabolism, sequestration, and detoxification. The gizzard also contained appreciable concentrations of the investigated metals. This may be explained by the feeding behavior of free-ranging domestic chickens, which frequently consume soil particles, insects, plant material, and other environmental substances during foraging. In contrast, metal concentrations in skeletal muscle were generally lower than those in the liver and gizzard. Nevertheless, the detection of elevated Pb concentrations in some muscle samples is particularly important from a food-safety perspective because skeletal muscle represents one of the principal edible portions consumed by humans.

An important observation of the present study was the difference in heavy-metal accumulation between free-ranging domestic chickens and the commercially reared broiler used as a reference specimen. In the broiler, Cd was detected only in the liver and gizzard, whereas Pb and Ni were not detected in the examined tissues. This pattern may reflect differences in exposure history and rearing conditions. Free-ranging domestic chickens are exposed to a wide range of environmental sources, including contaminated soil, roadside dust, waste materials, surface water, vegetation, and insects. In contrast, commercially reared broilers are generally maintained under controlled management systems with regulated feed and water supplies and limited contact with contaminated environmental matrices. Furthermore, commercial broilers have a substantially shorter production lifespan and are commonly marketed within approximately 40 days, providing considerably less time for environmental metals to accumulate. Similar differences in heavy-metal burdens between free-ranging and commercially reared poultry have been reported previously (Korish & Attia, 2020).

The concentrations observed in the present study are broadly comparable with findings reported from other developing countries where poultry have been exposed to environmental contamination. Hossain et al. (2023) detected heavy metals in edible portions of chickens and highlighted their potential implications for human health. Similarly, elevated concentrations of Pb, Cd, and Ni have been reported in poultry tissues from contaminated environments in Egypt, Iran, Bangladesh, and Nigeria. Differences in reported concentrations among studies may result from variation in environmental conditions, pollution sources, feeding behavior, age of birds, tissue type, farming systems, and analytical procedures. Nevertheless, the relatively greater accumulation of heavy metals in metabolically active organs, particularly the liver and gizzard, represents a consistent pattern reported in poultry exposed to contaminated environments.

The findings of the present investigation are of potential concern from a public-health perspective because repeated dietary exposure to heavy-metal-contaminated poultry products may contribute to chronic human exposure. Lead exposure has been associated with neurotoxicity, impaired cognitive development, hypertension, and cardiovascular effects, while cadmium is recognized for its nephrotoxic effects and has been associated with renal dysfunction, skeletal damage, and carcinogenicity. Nickel exposure may contribute to allergic reactions, oxidative stress, and other

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

adverse biological effects. Therefore, regular consumption of poultry tissues containing elevated concentrations of these metals could increase the potential long-term health risks to consumers (Hossain et al., 2023). The observed spatial and tissue-specific variation emphasizes the importance of routine monitoring of heavy metals in poultry raised in industrial, urban, and agricultural environments and highlights the need for appropriate environmental management and food-safety surveillance in the study region.

Conclusion

The present study demonstrated considerable spatial and tissue-specific variation in the accumulation of Cd, Pb, and Ni in locally raised domestic chickens from industrial, urban, and rural habitats of Nowshera District, Khyber Pakhtunkhwa. Several tissue samples contained heavy-metal concentrations above the reference permissible limits, particularly Pb in muscle and Cd in liver, indicating potential food-safety concerns. Cd showed significant variation among tissues, while habitat-related differences were observed for Cd in the gizzard and Ni in the liver. The highest Pb concentration was recorded in industrial-area chickens, whereas rural and urban birds also showed substantial metal accumulation. Compared with domestic chickens, the commercially reared broiler showed lower detectable metal levels, with Pb and Ni below detection limits. These findings indicate environmental exposure of free-ranging chickens to heavy metals and highlight the need for regular monitoring, improved environmental management, and food-safety surveillance. Larger studies are recommended to confirm these patterns and assess potential human health risks.

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Print ISSN 3007-3189

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