The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 4, Issue 2, 2026

BIOACCUMULATION PATTERNS OF LEAD AND CADMIUM IN WILD DUCKS: IMPLICATIONS FOR AVIAN HEALTH AND ECOSYSTEM MONITORING

Shahid Mahmood[*1], Rabia Amer[2], Aleena Iftikhar[3], Hammad Ul Hassan[4], Muhammad Faheem Sarwar[5], Fozia Jabeen[6], Majida Bibi[7], Mahnoor Madsar[8], Rimsha Shafaqat Ali[9]

[*1, 2, 3,4,5,6,7,8,9] *University of Gujrat, Gujrat 50700, Pakistan*

[*1]shahid.mahmood@uog.edu.pk

DOI: https://doi.org/10.5281/zenodo.18859866

Keywords
Wild ducks, Lead, Cadmium, Heavy metals, Body tissues, oxidative stress, Toxicity

Article History
Received: 29 December 2025
Accepted: 14 February 2026
Published: 28 February 2026

Copyright@Author
Corresponding Author: *
Shahid Mahmood

Abstract

Heavy metals are the hazardous elements which pose serious threats to human health if surpassed normal amounts. Heavy metals with the density greater than 5.0 g/cm³ are ingested by humans through the consumption of meat and other dairy products. A few major heavy metals include lead, cobalt, cadmium, copper, arsenic, zinc and mercury. They are specifically harmful to bird population like wild ducks which are frequently exposed to these heavy metals. We will review the effect of lead and cadmium in liver and kidneys of wild ducks. Wild ducks act as the bio indicators of environmental pollution in a particular area especially wetland ecosystems.as liver and kidney are the most effected tissues by heavy metals because of their physiological functions like detoxification and in few studies metal processing. These two organs serve as the site of accumulation for these metals. The toxic metals can find their way into numerous food sources via several routes, such as farming methods, agricultural soils, irrigation water, air, animal feed, and packaging materials. The prolonged exposure to these metals may have toxicological effects on reproduction and survival of the wild ducks. These metals may cause oxidative stress or histopathological alterations in the affected individuals. The factors that affect the accumulation of these metals includes specie-specific characteristics, age, sex, food habits and the level of environmental pollution. Lead (Pb) and cadmium (Cd) are persistent environmental toxicant that pose serious risk to aquatic ecosystem and avian biodiversity. Wild ducks are continuously exposed to these metals through polluted water, sediments, aquatic vegetation, invertebrates, and fish, making them effective biological indicators of wetland contamination. This Study reviews existing research on the sources, environmental pathways, toxicokinetics, and tissue-specific accumulation of lead and cadmium the heavy metals in wild ducks population. Particular attention is given to the liver and kidneys as major target organs because of their critical roles in detoxification, filtration, and metal storage. Prolonged exposure leads to oxidative stress, tissue damage, immune suppression, and long-term physiological dysfunction. The review also identifies specie -related difference in accumulation pattern influenced by feeding, ecology, habitat use, age, sex, and tropic position within aquatic food webs. Evidence further confirms that

bioaccumulation and biomagnification processes intensify metal concentrations across trophic levels, increasing ecological and biological risks. In addition to physiological toxicity, exposure to lead and cadmium is associated with reproductive impairment, neurological disruption, and behavioural abnormalities in birds. Overall, the findings establish wild ducks as reliable sentinel species for monitoring environmental pollution and ecosystem health. Continuous biomonitoring programs, stronger pollution control measures, and habitat -based conservation strategies are essential for minimizing heavy metal exposure and protecting avian biodiversity and aquatic ecosystem stability. This review also takes a dig at the eco toxicological effects of Pb and Cd in the wild ducks, emphasizing their implication as sentinel species for wetland pollution monitoring. Future research guidelines and moderation procedures are also considered, underlining the compulsion of more rigorous environmental laws and continuous biomonitoring initiatives. The goal of this thorough review is to upkeep conservation efforts and advance knowledge of heavy metal toxicity in avian fauna.

INTRODUCTION

Animals, plants, and people in the food chain are all impacted by heavy metal pollution, which originates from the air, soil, and water. Humans can use duck meat as a source of protein and as a marker of heavy metal contamination (Susanti, Widiyastuti et al. 2020). Due to their wide distribution, utilization of aquatic environments, and role in the food web, wild ducks serve as important bio indicators of environmental contamination. Their tissues, especially the liver and kidney, accumulate toxic metals like lead (Pb) and cadmium (Cd) as a result of exposure to pollutants through water, sediment, and food, making them accurate biomarkers for the health of ecosystems (Binkowski, Sawicka-Kapusta et al. 2013).One of the few ways through which Pb and Cd can enter aquatic systems are through the agricultural and industrial wastes. Certain mine activities and atmospheric accumulations also play key role in metal build up in aquatic ecosystems (Talukder, Ray et al. 2024).While Pb is mostly said to be sourced from militarized electronics and lead based batteries ,cd accumulation basically results from phosphate fertilizers run-off and metal extraction processes (ONONUGA 2016).Several researches have shown that in ducks the metal accumulation appears to be higher in kidney and liver because these are the key organs that perform the function of metal storage ,detoxification as well as the excretion of harmful substances (Bose-O'Reilly, Drasch et al. 2010).

Heavy Metal Pollution in aquatic ecosystem

Heavy Metal pose a global threat to aquatic ecosystems and biodiversity. Major sources include industrial waste, mining, agriculture and natural processes. Anthropogenic activities are the main driver of the contamination. Heavy metal degrades the water quality (PH, turbidity, oxygen levels). Toxic metals harm the aquatics animals (Sharma et al., 2025). Leads to bioaccumulation and biomagnification in food chains. Cause aquatic food web disturbance and also effect the ecosystem balance. Bioremediation and phytoremediation are key removal strategies (Sharma et al., 2025). Natural sources including volcanic eruptions, weathering of metal-rich rocks are also damaged the aquatic system. Heavy metals cause long-term environmental accumulation. Lead to chronic environmental pollution (Kapoor & Singh, 2021).

1.2 Sources of Lead and Cadmium Contamination

Studying the tissue and organs of wild mallard ducks (*Anas platyrhynchos*) provides valuable insight into environmental pollution and related toxicological threats from lead and cadmium. Sine heavy metals can be dangerous even in

minimal amounts, their presence represents a serious ecological and public health concern (Bombik et al., 2023). Continuous environmental monitoring of wild animals is therefore necessary to assess contamination levels and ecological safety (Bombik et al., 2023). Environmental lead remains a widespread pollutant with harmful biological effects across ecosystem. Birds are especially susceptible due to dietary exposure to potentially fatal lead concentrations. Its toxicity disturbs the physiological systems by increasing cellular oxidative stress and weakening immune defense mechanism (Williams etc al., 2017).

Lead and Cadmium: Environmental Pathways

The toxic metals may find their way into numerous food sources through several routes, such as farming methods, agricultural soils, irrigation water, air, animal feed, and packaging materials. These metals can't be degraded under heat, and persist in the environment for longer periods of time, leading to their buildup in various food sources (Xu, Jia et al. 2022).

Entry into Aquatic Food Chains

Sediment contamination is one of the primary methods through which metals like Pb and Cd enter aquatic food chains where they are destined to bind with organic matter and particulates (Yu, Ma et al. 2015). Bioaccumulation in plants occurs when aquatic plants and algae absorb these metals from water as well as sediments. Then the invertebrates like snails and insects that feed on these aquatic plants ingest the contaminated food .These invertebrates are a part of the food that ducks feed on.so in this way these metals enters the systems of wild ducks (Anderson and Padding 2015). Toxins may build up in the bodies of birds over time as a result of their consumption of fish that contain elevated levels of heavy metals in their tissues (Khan, Ashfaq et al. 2023). Excreting and removing these metals from the body is not easy so they continue to bio magnify in the body and end up reaching the much higher trophic levels.

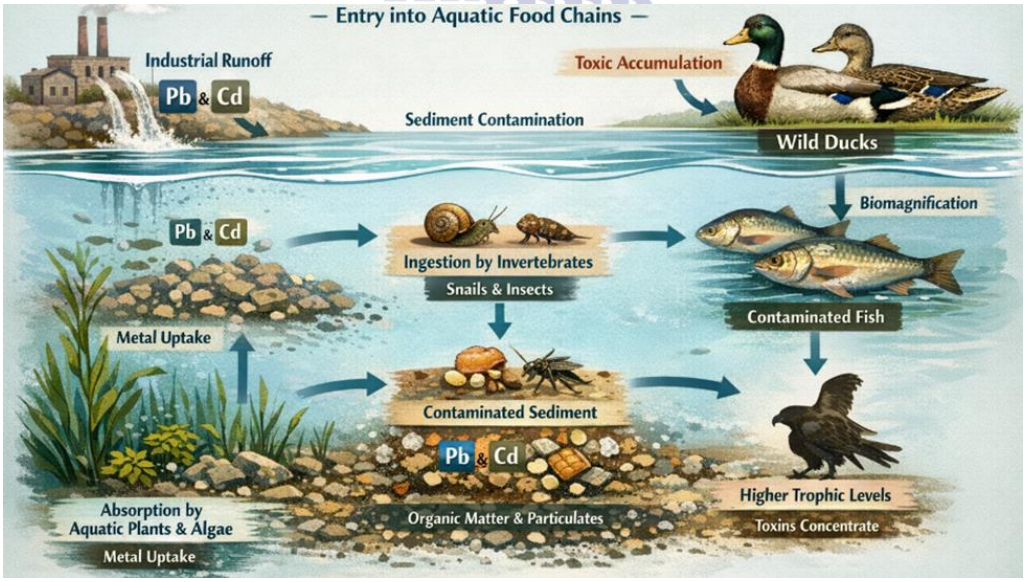


Fig. 01: Bioaccumulation pathway of Lead and Cadmium in Wild Ducks

Toxicokinetics in Wild Ducks

Absorption and Distribution

Wild ducks mainly take in Pb and Cd by consuming contaminated water, sediment, plants, and prey, with limited absorption through inhalation (Devreese, Croubels et al. 2018). Once ingested, Pb is absorbed in the intestines (5–15% bioavailability), whereas Cd absorption is greater with 3–8% in adults, and up to 20% in juveniles (Gasparik, Vladarova et al. 2010). The toxicity of

heavy metals has been established as a major threat, with numerous health complications connected to it. It is reported that heavy metals have harmful effects on the physiology of the animal body which interferes with the normal functioning of the body (Tahir and Alkheraije 2023).

Cadmium (Cd) and lead (Pb) are associated with metallothioneins (MTs)—metal-binding proteins that trap toxins, but they may become saturated, which can cause oxidative stress (Turolla, Cattaneo et al. 2018). The accumulation of cadmium in the proximal tubules results in nephrotoxicity over time, while lead is deposited in renal tissues due to the filtration process (Paixao, Silva et al. 2008). Lead (Pb) replaces calcium in hydroxyapatite crystals, resulting in the establishment of a long-term reservoir (Miedico, Iammarino et al. 2016).

Lead stays approximately 2 to 5 years in bones (a biomarker for chronic exposure), but only weeks to months in blood and soft tissues (Ciznar 2008). There is an extensive record of accumulation of lead in birds due to their intake of ammunition. The hunting ammunition has lead contained in it. The pH of the acid fluids in ducks' gizzards is approximately 2.5, whereas that of raptors is 1.8 (Anderson and Padding 2015). The liver is primarily responsible for excreting lead into the bile, which travels to the gastrointestinal tract and is eventually expelled in the stool. The kidneys' ability to filter urine has a far lower impact on the removal of lead (Sato, Ishii et al. 2022). It approximately remains 10 to 30 years in the kidneys, which is the longest duration for any heavy metal as a result of MT binding. (Järup & Åkesson, 2009).

Exposure to cadmium significantly transforms the main component of gut microbiota and considerably reduces the gut microbial alpha diversity. This results in the number of diseases in hosts. In addition to weakening immune system, it also affects the bone health (Sato, Ishii et al. 2022).There is very limited excretion and urinary excretion takes place solely following damage to the proximal tubule (Järup 2003).

Tissue Specific accumulation pattern

The study examined the heavy metal accumulation in feathers, liver, kidney tissues of 37 bird species in Thailand. Species-related variation in metal residues was found in the liver, and kidneys, but not in feather samples. Granivorous birds Showed higher cadmium (Cd) accumulation in internal organs compare to water birds (Khwankitrittiual et al., 2024). Lead (Pb) level exceeded toxic threshold in liver (>15ppm) and feathers (4>ppm) poisoning risk and reproductive impairment. Cadmium in kidney above save limit (2-8ppm), reflecting increased environmental exposure. Strong tissue correlations showed that liver and kidney samples can substitute for each other in metal monitoring studies. Feather sample used to estimate lead concentration in liver tissue. This shows wild birds are effective bioindicators of heavy metal pollution (Khwankitrittiual et al., 2024).

The study assessed heavy metal exposure in wild ducks collected from a hunting area near a fish farm in Donji Miholjac, Eastern Croatia. Liver tissue from 20 ducks was analyzed, including 10 Mallards and 10 Common Pochards. Samples were tested for cadmium, mercury, lead, and arsenic using flame atomic absorption spectrophotometry. A statistically significant species difference was observed only for cadmium levels ($P \leq 0.01$). No significant differences in metal accumulation were found between males and females within each species (Italian Journal of Animal Science, 2009). Common Pochards show greater sensitivity towards cadmium accumulation. Mallards show greater sensitivity towards lead. This study highlights the species-specific bioindicator role in monitoring heavy metal pollution and its effects on the environment (Italian Journal of Animal Science, 2009).

Impacts of Accumulation

Lead is harmful to physiological health; leads to developmental disorders of the central nervous system, diminished immunity, renal failure, fatigue, alterations in behavior, diarrhea, loss of appetite, and mortality. Cadmium deteriorates physiological condition; reduces reproductive

capacity and breeding outcomes; causes deterioration in egg quality and disturbances in embryogenesis (Bombik, Bombik et al. 2023). Lead and cadmium are co-factors in the formation of lesions in kidney and liver (Binkowski, Sawicka-Kapusta et al. 2013).

Heavy metals can have adverse effects when accumulate in the human body through consumption of meat derived by cattle such as beef. Cadmium is even known to cause cancer in humans. Some nutrients which are essential for the body could be depleted due to the consumption of food contaminated with heavy metals. It could result in the reduced efficiency of immunological responses .it is also associated with bad reproductive health .One of the impacts is diseases due to malnutrition (Jomova, Alomar et al. 2025).

Oxidative stress

The oxidative state and reactivity of metals with other substances are linked to their toxicity. Lead can increase ROS generation, which can lead to oxidative damage to proteins, lipids, and DNA. Although cadmium cannot directly produce free radicals, exposure can cause lipid peroxidation in tissues (Koivula and Eeva 2010). In case of liver and kidneys working as the main organs for storage, aquatic birds exhibit a greater tendency in comparison to terrestrial birds to harbor higher levels of metals and arsenic, hence enhancing oxidative damage. Such variables as taxonomic identity, tissue type, ecological niche and nutritional regime have a significant effect on the load of pollutants and the manifestations of physiological stress (Kanwal, Abbasi et al. 2020).

Physiological and Reproductive effects on Avian Health

Reproductive organs are highly sensitive to environmental toxin. Cadmium, lead, mercury are major reproductive toxicant. Human activities are the main source of heavy metals in the environment. Epidemiological studies link these metal infertility and reproductive organs. Experimental animal studies confirm structural and functional damaged. Testes and Ovaries are highly vulnerable due to the higher cellular activity (Massanyi et al.,2020).Ovarian effects include the reduced follicular growth, follicular atresia, Corpus luteum regeneration, estrous cycle disturbance. Testicular effects include the damage to seminiferous tubules, altered testicular stroma, decreased sperm count, reduced motility and viability (Massanyi et al., 2020).

3.3 Behavioral and Neurological impacts

Brain tissue of long-tailed ducks was examined to determine concentration of essential and toxic metal including iron, zinc, copper, lead and cadmium. Most metals showed no significant gender differences, but cadmium was substantially higher in males. Lead contamination was detected at harmful levels in a notable number of individuals (Kalisinska & Szuberla ,1996).Correlation analysis showed positive metal association(Zn-Mn, Cu-Mn, Cu-Fe, Pb-Fe)and a negative interaction between Pb and Zn. Female birds demonstrated an additional positive relationship between Pb and Fe. These pattern indicates that metal accumulation in avian brains is shaped by both natural biological functions and environmental pollution pressure (Kalisinska & Szuberla, 1996).Dietary exposure to dieldrin in mallard ducks produced measurable toxic, neurological, and behavioural changes. Brain analysis showed a dose-dependent decline in monoamine neurotransmitters (serotonin, norepinephrine, and dopamine).Inhibitory neurotransmission (GABA) remained unaffected (Sharma et al., 1977).Liver analysis elevated drug - metabolizing enzyme activity following sublethal pesticide exposure. Significant biochemical shifts were found in liver proteins and nucleic acids, indicating cellular level effects. Behavioral observation showed that exposed drakes had reduced initiative and social dominance during confrontations. Stufy highlights potential links between neurochemical disruption and insecticide- induced neurotoxicity (Sharma et al., 1977).

4. Wild Ducks as Bioindicators of environmental pollution

Birds function are reliable biological tools for evaluating environmental quality and ecological

balance. Their presence and abundance provide direct insight in ecosystem stability and resilience. Decline in its population often signals pollution, habitat loss and ecosystem disturbance. Their sensitivity making them effective early-warning indicators. They contribute to the Ecological processes through pest control, pollination and seed dispersal (Khan et al., 2025).Bird -based monitoring provides a low cost and efficient method for environmental evaluation. Bioindicators play a central role in biodiversity conservation, risk assessment, and sustainable ecosystem management (Khan et al., 2025).Cadmium function as a dangerous environmental contaminant with severe biological impacts on wildlife. The study measured the level of it's in the liver and kidney tissue of 85 wild birds from different regions of Japan. Concentrations widely varied ranging from non-detectable to high level in both organs. Birds exposed to the oil pollution exhibited elevated Cadmium concentrations. These findings demonstrate that birds mirror environmental contamination pattern. This research confirms the value of the wild birds as Bioindicators of environmental pollution (Mochizuki et al., 2002).

4.1 Role of Wild Ducks in Ecosystem Monitoring

Habitat selection in boreal wetlands is regulated by complex interactions between food supply, habitat structure, and ecological conditions, but these relationships remain insufficiently documented. Researchers surveyed broad-rearing female ducks and their offspring across four boreal species to assess how environmental structure and food resources influence wetland use (Nummi et al., 2013).The analysis demonstrate the wetland use patterns were controlled by both habitat configuration and food availability, with varying importance among species. Common Goldeneye habitat use for strongly linked to aquatic invertebrate abundance and availability of large emerging insects. Mallards depends on a combined effect of habitat complexity emerging insect availability. These ecological differences suggest that wetlands conservation and management programs must integrate specie-specific habitat and food requirements for success (Nummi et al., 2013).Expansion of agriculture, cities, and industrial development has caused widespread loss of coastal and inland wetlands, leading to major decline of waterbird habitats. Habitat degradation in wetlands and nearby upland areas has produced long-term negative on several duck and rail populations. Long-term conservation programs are often perceived as water-fowl focused, field surveys demonstrate benefits for hundreds non-waterfowl species. The creation and management of wetlands are helpful for supporting waterbirds across seasonal life stages (Tori et al., 2002).

Global Scenario

In South Asian countries Cadmium contagion is intensely allied with Phosphate fertilizer application (Alloway, 2013), Electroplating and metal finishing industries (Ali et al., 2019), Coal-fired power plants (Kumar et al., 2020) and Textile and tannery effluents. While Lead distributes to Liver shows short-term accumulation), Kidney have intermediate storage) and Bone reflects long-term deposition (Fig. 02). Bone lead reflects cumulative lifetime exposure because Pb substitutes for calcium in hydroxyapatite crystals (Scheuhammer, 1987). Bone contamination levels steadily surpass Liver levels (Table 01), confirming chronic exposure of the Liver levels, where the levels above 2 µg/g propose that these concentrations reflects environmental contamination (Scheuhammer, 1987). While table 02 shows that the potential renal concentrations approaching or beyond 15 µg/g indicate potential nephrotoxicity (Eisler, 1985).

South Asian studies report Pb bioaccumulation leads to reduced hemoglobin levels, elevated erythrocyte protoporphyrin and altered leukocyte profiles. Whereas, Cadmium exposure is associated with the elevated serum creatinine, renal tubular protein leakage and increased metallothionein expression (Nordberg et al., 2015)

Wild ducks studies provide multiple aspects and advantages as bioindicators because Wild ducks

are preferred to study because they shows wide migratory distribution, direct sediment interaction, intermediate trophic position and availability through regulated hunting. Feather analysis provides non-lethal sampling options (Burger, 1993). However, standardized protocols are lacking across South Asian monitoring programs. Integrated monitoring should combine sediment metal analysis, Invertebrate contamination, tissue absorption measurement, and biomarker assessment and population health indicators.

Despite increasing studies, critical gaps includes lack of long-term population datasets, insufficient experimental toxicology on local species, limited biomarker standardization, weak enforcement of hunting ammunition regulations and minimal assessment of combined pollutant effects

Whereas, the mitigation strategies should include phasing out lead ammunition, strengthening industrial effluent regulation, sediment remediation in contaminated wetlands, monitoring fertilizer cadmium content and establishing wildlife contaminant surveillance programs. Regional cooperation under international conservation agreements is necessary to address transboundary contamination.

Table 01: Reported Lead Concentrations in Wild Ducks of South Asia

Country	Species	Tissue	Reported Range (µg/g dw)	Reference
Pakistan	Mallard	Liver	2–9	Raza et al., 2020
Pakistan	Northern Pintail	Bone	15–40	Ali et al., 2019
India	Gadwall	Liver	1.8–7.5	Singh et al., 2017
Bangladesh	Mixed Anatidae	Liver	3–10	Islam et al., 2018
India	Common Teal	Bone	12–35	Sharma et al., 2021

IEER
Institute for Excellence in Education & Research

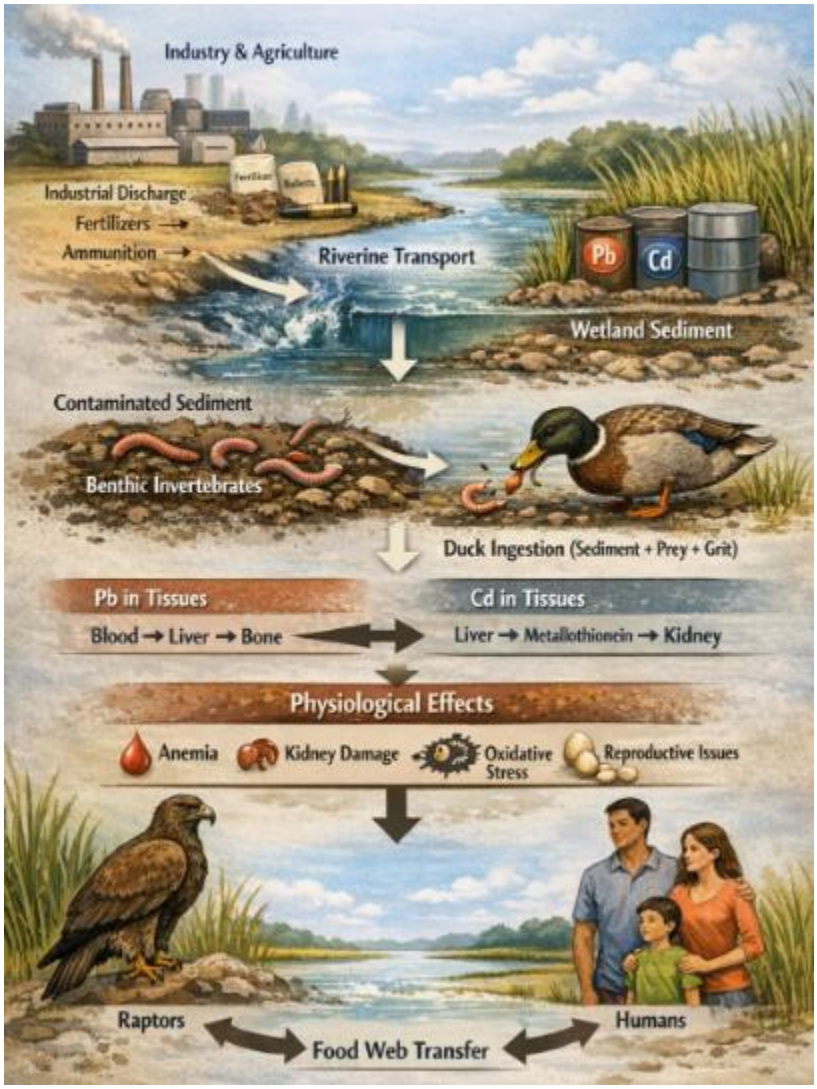


Fig. 02. Conceptual Model of Pb and Cd Bioaccumulation in South Asian Wetlands

Table 2. Reported Cadmium Concentrations in Wild Ducks of South Asia

Country	Species	Tissue	Reported Range (µg/g dw)	Reference
Pakistan	Mallard	Kidney	8–18	Khan et al., 2016
India	Eurasian Wigeon	Kidney	6–15	Sharma et al., 2021
Bangladesh	Mixed Anatidae	Kidney	5–12	Islam et al., 2018
Pakistan	Northern Pintail	Liver	2–6	Ali et al., 2019

Heavy metals like lead (Pb) and cadmium (Cd) pose ongoing risks to wild ducks due to environmental pollution from sources such as mining and hunting ammunition. Where the **regional variations** regarding higher metal levels are commonly found in ducks from industrialized or mining-affected areas compared to rural or reference sites. Health risks shows Sublethal effects, such as enzyme inhibition and behavioral changes, appear more prevalent than immediate mortality, but debates exist on long-term population impacts. Monitoring potential of Ducks' migratory habits make them effective sentinels, but interpretations should consider

species differences and exposure routes. Comparative data across species reveal variations (Table 03). For example, in Croatian wetlands, Common Pochards (*Aythya ferina*) had significantly higher liver Cd than Mallards, while Mallards showed elevated Pb, suggesting species-specific foraging or metabolic differences (P≤0.01) (Florijančić et al., 2009).

Table 03. Reported Lead and Cadmium levels in Wild Ducks of Northern Hemisphere

Location	Species	Tissue	Pb Concentration (µg/g,)	Cd Concentration (µg/g)	References
Northern Idaho	Wood Duck	Blood	Up to 8	N/A	Blus et al., 1993
Northern Idaho	Wood Duck	Liver	Up to 14	N/A	Blus et al., 1993
Northern Idaho	Wood Duck	Kidney	N/A	1–20	Blus et al., 1993
Northern Idaho	Mallard	Blood	Up to 10.2 (nestlings)	N/A	Blus et al., 1995
Northern Idaho	Mallard	Liver	Up to 2.8 (nestlings)	N/A	Blus et al., 1995
Northern Idaho	Mallard	Kidney	N/A	Up to 7.5	Blus et al., 1995
Poland	Mallard	Breast Muscle	0.0649–0.0986 (higher in Leszno)	0.0146–0.0189 (higher in Leszno)	Bombik et al., 2023
Poland	Mallard	Liver	0.0778–0.1758 (higher in Leszno)	0.0336–0.0518 (higher in Siedlce)	Bombik et al., 2023)
Croatia	Mallard	Liver	Higher in Mallard	Higher in Pochard (P≤0.01)	Florijančić et al., 2009

Conclusion

Due to the accumulation of large amounts of heavy metals in the renal and hepatic tissues that often surpass the safety criteria, wild ducks are considered to be the bio indicators of environmental pollution. The long-term exposure to the heavy metals have significant impacts on the ecosystem's general health due to effects like oxidative stress, liver damage, and kidney dysfunction. It also compromises the safety of people who consume infested waterfowl. Due to industrial and agricultural overspill, metal concentrations in ducks have increased considerably which highlights the urge to take immediate steps to devise control strategies and improve ongoing animal monitoring. Even though current data explicitly shows that wild ducks are critical bio indicators of aquatic ecosystem health, there still arise some unanswered questions about synergistic effects with other contaminants, specie-specific accumulation patterns and long term population implications that are long-term. Future studies should focus more on developing moderation policies to reduce metal imports into dynamic waterfowl habitats, regulating monitoring procedures for different ecosystems, and carrying out experiments on sub lethal impacts. These results underline how imperative it is to take

account of wildlife toxicological data in environmental management plans in to shield avian populations and human consumers from the risks related with heavy metal exposure. The results of this study demonstrate that lead and cadmium contamination represents a persistent and expanding threat to aquatic ecosystems and bird health. Wild ducks because of their ecological function, dietary habits, dependence on wetland habitats. Accumulate significant levels of these metals through bioaccumulation and biomagnification mechanisms. The liver and kidney are the most affected organs, consistently showing patterns of metal deposition, oxidative injury, and functional decline. Beyond physiological toxicity, chronic exposure leads to reproductive disorders, immune dysfunction, neurological impairment, and behavioural changes, collectively threatening population stability and species persistence. Species-specific accumulation trends further indicate that ecological niche, habitat preference and dietary habits strongly influence contamination vulnerability. These finding emphasize the long-term biomonitoring programs, strict regulation of industrial, agricultural, and mining discharge sustained wetland conservation. Preserving wetlands from heavy metals not only conserve the bird but also have a positive impact on the ecosystem balance, food web stability, and overall environmental stability.

REFERENCES

Ali, Z., Malik, R. N., & Qadir, A. (2019). Heavy metal contamination in wetland sediments of Pakistan and implications for avian species. Environmental Monitoring and Assessment, 191, 1–14.

Alloway, B. J. (2013). Heavy metals in soils (3rd ed.). Springer.

Anderson, M. G. and P. I. Padding (2015). "The North American approach to waterfowl management: synergy of hunting and habitat conservation." International Journal of Environmental Studies 72(5): 810-829.

Binkowski, Ł. J., K. Sawicka-Kapusta, J. Szarek, E. Strzyżewska and M. Felsmann (2013). "Histopathology of liver and kidneys of wild living Mallards Anas platyrhynchos and Coots Fulica atra with considerable concentrations of lead and cadmium." Science of the Total Environment 450: 326-333.

Blus, L. J., Henny, C. J., Hoffman, D. J., & Grove, R. A. (1993). Accumulation and effects of lead and cadmium on wood ducks near a mining and smelting complex in Idaho. *Ecotoxicology*, *2*(2), 139-154.

Blus, L. J., Henny, C. J., Hoffman, D. J., & Grove, R. A. (1995). Accumulation in and effects of lead and cadmium on waterfowl and passerines in northern Idaho. *Environmental Pollution*, *89*(3), 311-318.

Bombik, E., A. Bombik and K. Pietrzkiewicz (2023). "Content of lead and cadmium in the tissues and organs of the wild mallard duck (Anas platyrhynchos L.) Depending on the region of Poland where it is harvested." Animals 13(21): 3327.

Bose-O'Reilly, S., G. Drasch, C. Beinhoff, A. Tesha, K. Drasch, G. Roider, H. Taylor, D. Appleton and U. Siebert (2010). "Health assessment of artisanal gold miners in Tanzania." Science of the total Environment 408(4): 796-805.

Burger, J. (1993). Metals in avian feathers: Bioindicators of environmental pollution. Reviews in Environmental Toxicology, 5, 203–311.

Cain, B. W., Sileo, L., Franson, J. C., & Moore, J. (1983). Effects of dietary cadmium on mallard ducklings. *Environmental Research*, *32*(3), 286-297.

Ciznar, I. (2008). Expanding the EcoHealth Toolkit, Springer.

Devreese, M., S. Croubels, S. De Baere, R. Gehring and G. Antonissen (2018). "Comparative toxicokinetics and plasma protein binding of ochratoxin an in four avian species." Journal of agricultural and food chemistry 66(9): 2129-2135.

Eisler, R. (1985). Cadmium hazards to fish, wildlife, and invertebrates. Biological Report 85(1.2).

Florijančić, T., Opačak, A., Bošković, I., Jelkić, D., Ozimec, S., Bogdanović, T., ... & Puškadija, Z. (2009). Heavy metal concentrations in the liver of two wild duck species: influence of species and gender. *Italian Journal of Animal Science*, *8*(sup3), 222-224.

Florijančić, T., Opačak, A., Bošković, I., Jelkić, D., Ozimec, S., Bogdanović, T. ... & Puškadija, Z. (2009). Heavy metal concentrations in the liver of two wild duck species: influence of species and gender. Italian Journal of Animal Science, 8(sup3), 222-224.

Gasparik, J., D. Vladarova, M. Capcarova, P. Smehyl, J. Slamecka, P. Garaj, R. Stawarz and P. Massanyi (2010). "Concentration of lead, cadmium, mercury and arsenic in leg skeletal muscles of three species of wild birds." Journal of Environmental Science and Health Part A 45(7): 818-823.

Islam, M. S., Ahmed, M. K., & Raknuzzaman, M. (2018). Metal contamination in Bangladeshi wetlands and implications for waterbirds. Ecotoxicology and Environmental Safety, 150, 230– 238.

Järup, L. (2003). "Hazards of heavy metal contamination." British medical bulletin 68(1): 167-182.

Kalisińska, E., & Szuberla, U. (1996). Heavy metals in the brain of long-tailed duck (Clangula hyemalis) wintering in the Pomeranian Bay, Poland. Biological trace element research, 55(1), 191-197.

Kanwal, S., N. A. Abbasi, M. J. I. Chaudhry, S. R. Ahmad and R. N. Malik (2020). "Oxidative stress risk assessment through heavy metal and arsenic exposure in terrestrial and aquatic bird species of Pakistan." Environmental Science and Pollution Research 27(11): 12293-12307.

Kapoor, D., & Singh, M. P. (2021). Heavy metal contamination in water and its possible sources. In Heavy metals in the environment (pp. 179-189). Elsevier.

Khan, B. N., Y. Ashfaq, N. Hussain, U. Atique, T. Aziz, M. Alharbi, T. H. Albekairi and A. F. Alasmari (2023). "Elucidating the effects of heavy metals contamination on vital organ of fish and migratory birds found at fresh water ecosystem." Heliyon 9(11).

Khan, M. A., Ahmad, I., & Rahman, Z. (2016). Cadmium accumulation in irrigation-fed wetlands of Punjab, Pakistan. Environmental Science and Pollution Research, 23, 12345–12356.

Khan, M., Khalid, S., & Khalid, M. A. (2025). Birds as bioindicators of environmental health. Biodiversity in India: Implementation and barriers of regulatory acts, 01-17.

Khwankitrittikul, P., Poapolathep, A., Poapolathep, S., Prasanwong, C., Kulprasertsri, S., & Khidkhan, K. (2024). Species differences and tissue distribution of heavy metal residues in wild birds. Animals, 14(2), 308.

Koivula, M. J. and T. Eeva (2010). "Metal-related oxidative stress in birds." Environmental pollution 158(7): 2359-2370.

Kumar, V., Sharma, A., & Pandita, S. (2020). Heavy metal pollution in India: Sources and ecological risks. Chemosphere, 246, 125735.

Massányi, P., Massányi, M., Madeddu, R., Stawarz, R., & Lukáč, N. (2020). Effects of cadmium, lead, and mercury on the structure and function of reproductive organs. Toxics, 8(4), 94.

Miedico, O., M. Iammarino, G. Paglia, M. Tarallo, M. Mangiacotti and A. E. Chiaravalle (2016). "Environmental monitoring of the area surrounding oil wells in Val d'Agri (Italy): element accumulation in bovine and ovine organs." Environmental monitoring and assessment 188(6): 338.

Mochizuki, M., Hondo, R., Kumon, K., Sasaki, R., Matsuba, H., & Ueda, F. (2002). Cadmium contamination in wild birds as an indicator of environmental pollution. Environmental Monitoring and Assessment, 73(3), 229-235.

Nordberg, G. F., Fowler, B. A., & Nordberg, M. (2015). Handbook on the toxicology of metals (4th ed.). Academic Press.

Nummi, P., Paasivaara, A., Suhonen, S., & Pöysä, H. (2013). Wetland use by brood-rearing female ducks in a boreal forest landscape: the importance of food and habitat. Ibis, 155(1), 68-79.

Ononuga, A. O. (2016). Heavy metals accumulati on in soil, water, maize and chicken at ori-ile battery waste dumpsite, Olodo, Ibadan, Nigeria. (Doctoral dissertation)

Paixao, S. M., L. Silva, A. Fernandes, K. O'Rourke, E. Mendonça and A. Picado (2008). "Performance of a miniaturized algal bioassay in phytotoxicity screening." Ecotoxicology 17(3): 165-171.

Raza, A., Qadir, A., & Malik, R. N. (2020). Lead contamination in riverine wetlands of Punjab, Pakistan. Environmental Pollution, 259, 113890.

Sato, H., C. Ishii, S. M. Nakayama, T. Ichise, K. Saito, Y. Watanabe, K. Ogasawara, R. Torimoto, A. Kobayashi and T. Kimura (2022). "Behavior and toxic effects of Pb in a waterfowl model with oral exposure to Pb shots: Investigating Pb exposure in wild birds." Environmental pollution 308: 119580.

Scheuhammer, A. M. (1987). The chronic toxicity of aluminum, cadmium, mercury, and lead in birds. Environmental Pollution, 46, 263–295.

Sharma, M., Kant, R., Sharma, A. K., & Sharma, A. K. (2025). Exploring the impact of heavy metals toxicity in the aquatic ecosystem. International Journal of Energy and Water Resources, 9(1), 267-280.

Sharma, P., Singh, S., & Kaur, H. (2021). Heavy metal bioaccumulation in migratory waterfowl of northern India. Ecotoxicology, 30, 145–158.

Sharma, R. P., Winn, D. S., & Low, J. B. (1977). Toxic, neurochemical and behavioral effects of dieldrin exposure in mallard ducks. Archives of Environmental Contamination and Toxicology, 5(1), 43-53.

Singh, R., Gautam, N., & Mishra, A. (2017). Sediment-associated heavy metals in Ganges wetlands. Environmental Monitoring and Assessment, 189, 123.

Smits, J. E., & Fernie, K. J. (2013). Avian wildlife as sentinels of ecosystem health. Comparative Immunology, Microbiology and Infectious Diseases, 36(3), 333-342.

Susanti, R., K. Widiyastuti, A. Yuniastuti and F. Fibriana (2020). "Feed and water management may influence the heavy metal contamination in domestic ducks from Central Java, Indonesia." Water, Air, & Soil Pollution 231(4): 177.

Talukder, P., R. Ray, M. Sarkar, A. Das and S. Chakraborty (2024). "Adverse effects of mining pollutants on terrestrial and aquatic environment and its remediation." Environmental Quality Management 33(4): 595-610.

Tori, G. M., McLeod, S., McKnight, K., Moorman, T., & Reid, F. A. (2002). Wetland conservation and Ducks Unlimited: Real world approaches to multispecies management. Waterbirds, 115-121.

Turolla, A., M. Cattaneo, F. Marazzi, V. Mezzanotte and M. Antonelli (2018). "Antibiotic resistant bacteria in urban sewage: Role of full-scale wastewater treatment plants on environmental spreading." Chemosphere 191: 761-769.

Williams, R. J., Holladay, S. D., Williams, S. M., & Gogal, R. M. (2017). Environmental lead and wild birds: a review. Reviews of Environmental Contamination and Toxicology Volume 245, 157-180.

Yu, Q., J. Ma, P. Zou, H. Lin, W. Sun, J. Yin and J. Fu (2015). "Effects of combined application of organic and inorganic fertilizers plus nitrification inhibitor DMPP on nitrogen runoff loss in vegetable soils." Environmental science and pollution research 22(1): 472-481.

Anderson, M. G. and P. I. Padding (2015). "The North American approach to waterfowl management: synergy of hunting and habitat conservation." International Journal of Environmental Studies 72(5): 810-829.

Binkowski, Ł. J., K. Sawicka-Kapusta, J. Szarek, E. Strzyżewska and M. Felsmann (2013). "Histopathology of liver and kidneys of wild living Mallards Anas platyrhynchos and Coots Fulica atra with considerable concentrations of lead and cadmium." Science of the Total Environment 450: 326-333.

Bombik, E., A. Bombik and K. Pietrzkiewicz (2023). "Content of lead and cadmium in the tissues and organs of the wild mallard duck (Anas platyrhynchos L.) depending on the region of Poland where it is harvested." Animals 13(21): 3327.

Bose-O'Reilly, S., G. Drasch, C. Beinhoff, A. Tesha, K. Drasch, G. Roider, H. Taylor, D. Appleton and U. Siebert (2010). "Health assessment of artisanal gold miners in Tanzania." Science of the total Environment 408(4): 796-805.

Ciznar, I. (2008). Expanding the EcoHealth Toolkit, Springer.

Devreese, M., S. Croubels, S. De Baere, R. Gehring and G. Antonissen (2018). "Comparative toxicokinetics and plasma protein binding of ochratoxin A in four avian species." Journal of agricultural and food chemistry 66(9): 2129-2135.

Gasparik, J., D. Vladarova, M. Capcarova, P. Smehyl, J. Slamecka, P. Garaj, R. Stawarz and P. Massanyi (2010). "Concentration of lead, cadmium, mercury and arsenic in leg skeletal muscles of three species of wild birds." Journal of Environmental Science and Health Part A 45(7): 818-823.

Järup, L. (2003). "Hazards of heavy metal contamination." British medical bulletin 68(1): 167-182.

Jomova, K., S. Y. Alomar, E. Nepovimova, K. Kuca and M. Valko (2025). "Heavy metals: toxicity and human health effects." Archives of toxicology 99(1): 153-209.

Kanwal, S., N. A. Abbasi, M. J. I. Chaudhry, S. R. Ahmad and R. N. Malik (2020). "Oxidative stress risk assessment through heavy metal and arsenic exposure in terrestrial and aquatic bird species of Pakistan." Environmental Science and Pollution Research 27(11): 12293-12307.

Khan, B. N., Y. Ashfaq, N. Hussain, U. Atique, T. Aziz, M. Alharbi, T. H. Albekairi and A. F. Alasmari (2023). "Elucidating the effects of heavy metals contamination on vital organ of fish and migratory birds found at fresh water ecosystem." Heliyon 9(11).

Koivula, M. J. and T. Eeva (2010). "Metal-related oxidative stress in birds." Environmental pollution 158(7): 2359-2370.

Miedico, O., M. Iammarino, G. Paglia, M. Tarallo, M. Mangiacotti and A. E. Chiaravalle (2016). "Environmental monitoring of the area surrounding oil wells in Val d'Agri (Italy): element accumulation in bovine and ovine organs." Environmental monitoring and assessment 188(6): 338.

ONONUGA, A. O. (2016). HEAVY METALS ACCUMULATI ON IN SOIL, WATER, MAIZE AND CHICKEN AT ORI-ILE BATTERY WASTE DUMPSITE, OLODO, IBADAN, NIGERIA.

Paixao, S. M., L. Silva, A. Fernandes, K. O'Rourke, E. Mendonça and A. Picado (2008). "Performance of a miniaturized algal bioassay in phytotoxicity screening." Ecotoxicology 17(3): 165-171.

Sato, H., C. Ishii, S. M. Nakayama, T. Ichise, K. Saito, Y. Watanabe, K. Ogasawara, R. Torimoto, A. Kobayashi and T. Kimura (2022). "Behavior and toxic effects of Pb in a waterfowl model with oral exposure to Pb shots: Investigating Pb exposure in wild birds." Environmental pollution 308: 119580.

Susanti, R., K. Widiyastuti, A. Yuniastuti and F. Fibriana (2020). "Feed and water management may influence the heavy metal contamination in domestic ducks from Central Java, Indonesia." Water, Air, & Soil Pollution 231(4): 177.

Tahir, I. and K. A. Alkheraije (2023). "A review of important heavy metals toxicity with special emphasis on nephrotoxicity and its management in cattle." Frontiers in veterinary science 10: 1149720.

Talukder, P., R. Ray, M. Sarkar, A. Das and S. Chakraborty (2024). "Adverse effects of mining pollutants on terrestrial and aquatic environment and its remediation." Environmental Quality Management 33(4): 595-610.

Turolla, A., M. Cattaneo, F. Marazzi, V. Mezzanotte and M. Antonelli (2018). "Antibiotic resistant bacteria in urban sewage: Role of full-scale wastewater treatment plants on environmental spreading." Chemosphere 191: 761-769.

Xu, H., Y. Jia, Z. Sun, J. Su, Q. S. Liu, Q. Zhou and G. Jiang (2022). "Environmental pollution, a hidden culprit for health issues." Eco-Environment & Health 1(1): 31-45.

Yu, Q., J. Ma, P. Zou, H. Lin, W. Sun, J. Yin and J. Fu (2015). "Effects of combined application of organic and inorganic fertilizers plus nitrification inhibitor DMPP on nitrogen runoff loss in vegetable soils." Environmental science and pollution research 22(1): 472-481.

IEER
Excellence in Education & Research