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TOXICO-PATHOLOGICAL EFFECTS OF HEAVY METALS ON GOAT VISCERAL ORGANS IN PAKISTAN: A COMPREHENSIVE REVIEW

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Abstract

The accumulation of dangerous heavy metals in the body of food producing animals is an increasing health issue of concern worldwide and more particularly in low and middle income countries like Pakistan. This review will look at the available literature on the absorption and retention of different toxic elements in the internal organs of goats, which forms an important part of the livestock industry in the country. Goats often consume polluted soil, vegetation and water in regions of industrial discharge, mining, and irrigation of untreated wastewater because of their free-ranging feeding behavior. The liver and kidneys are the organs in which metal deposition is the greatest, and in which the pathological conditions of cell degeneration, tissue death, and disrupted organ functions are observed. Some investigations carried out in other cities in Pakistan reported metal levels that habitually exceeded internationally advised safety limits. In terms of public health, the results are frightening, because chronic food contamination with chromium and mercury already surpasses the safe daily exposure levels of these elements in adults, with liver being the most severe threat to the consumers. Those gaps in knowledge are significant, as there are few studies that focus on more than one organ, long-term observations are not conducted, and geographical coverage is not complete. The future directions are to design country-wide surveillance systems, use sensitive analysis techniques like atomic absorption spectroscopy, and determine risk characterization in detail by using species-specific exposure indices. It is necessary to develop national regulatory limits to safeguard human health against metal contamination that is produced in the livestock production chain.

INTRODUCTION

The heavy metals are traditionally defined as metals that are dense, more than 4.5g/ cm^3 have an atomic weight between 63.5 to 200.6 gram. The heavy metals occur naturally in the earth crust, in the air and water. The heavy metals can also be accumulated in the food chain. The heavy metals can lead to harmful effects among human beings and the possibility of being exposed to these elements has been increased due to anthropogenetic and manufacturing activities (Jannetto & Cowl, 2023). The heavy metals are a great danger to living organisms and environment due to their features, primarily, their toxicity, and the high capability to accumulate. The metallic ions cannot be broken down to the end components in comparison to the organic contaminants which are highly influenced by chemical and biological degradation (Jadaa & Mohammed, 2023).

The heavy metals can be taken up through various pathways such as through the skin, oral or through inhalation. After being metabolized, these elements can start accumulating; in other instances, some of the heavy metals can replace important trace elements. This can lead to the disruption of the biological activity of different hormones, enzymes, metabolic procedures, and functions in the Central nervous system. Hence, it is significant to identify possible signs of heavy metal poisoning and offer early treatment to the victim (Jannetto & Cowl, 2023). The heavy metals lead to severe health issues thus the accurate determination of their residues is taken seriously. The toxic effects of heavy metals in the body include nervous system syndromes, renal failure, genetic alterations, cancer types, neurological ailments, respiratory disorders, and cardiovascular diseases, weakening of immune system and sterility (Ziarati et al., 2018).

These metals can be formed under different natural conditions including volcanic outbreak, mineral-rich spring water, corrosion of metal structures, and microorganism activity in soil and water. The mining, industrial and combustion processes carried out by industries are also taking the dominant role in the proliferation of these harmful metals in the environment8. As a result of modern industrialization, Lead and cadmium toxicity have caused a high degree of damage to the flora and fauna (Kanwal et al., 2024).

The livestock animals have a wide range of sources of heavy metals contamination , industrial wastes being one of the important sources (Elheddad et al., 2021). Industrial wastewater has dangerous contaminants such as Cr, which are released into the soil and water bodies (Afzal & Mahreen, 2024). This pollution is dangerous to livestock since they may consume contaminated water or feed on contaminated fields. In the same vein, the emissions of automobiles cause metal pollution along the road sides. The grazing of livestock around roads subjected them to metal contaminations which negatively impact on their health (Ghorani-Azam et al., 2016).

Furthermore, heavy metals are introduced in the agricultural enterprises through the use of fertilizers (Rizzardini & Goi, 2014). Animals can also feed on crops produced in these contaminated soils where heavy metals collect in the body tissues of animals. Moreover, mining also contaminates the environment with toxic metals (Okereafor et al., 2020). Organisms in the mining field might be exposed to these wastes either directly through soil, water and plants which affect their well-being and efficiency (Afzal & Mahreen, 2024).

Pakistan's goat populations represent approximately 80 million goat heads. The majority of this goat production is performed on a household basis. Goat is one of the fastest growing species of domestic animals in Pakistan. With respect to the number of goat breeds and genetics, Pakistan is third in the world behind China and India as the largest producers of goat. In Pakistan, goats is primarily used for meat, but also produce milk, hair and skin. Goat meat represented 15 percent of the total meat produced in 2021 (Abdullah et al., 2024).

Goats managed to become semi-domesticated and able to thrive in areas that are not really suited for crop cultivation or raising other livestock. They can survive with very little water and tolerate hot temperatures. They're a common option for small farms in semi-arid and arid regions. All in all, goats are great forking animals because they can thrive under harsh conditions (Mazhangara et al., 2019).

The health dangers and toxic effects of heavy metals will depend on several aspects like the type that metal, length of time exposed to the metal, gender, age group, nutritious and functional status of animal, and the type of contact to metals. Therefore, the bioaccumulation of heavy metals in animals signifies a serious health risk to domestic animals that can adversely affect their production performance (Afzal & Mahreen, 2024). Heavy metal intoxication negatively affects the reproductive performance of males, including an impact on the growth and concentration of sperm and the motility of sperm cells (Ilieva et al., 2020) Contact of female goats with these heavy metals has a significant effect on the proportion of germinal vesicles that develop into oocytes, as well as the rate of oocyte maturity before an animal can. They are also affected by heavy metals

through the depression of the functions of the reproductive Endocrine System, including the release of oocytes from Graafian cells, and eventually by impairing the overall breeding potential of female animals (Dutta et al., 2022 ; Fort et al., 2001).

Milk and meat produced on commercial farms are at risk of being negatively impacted by heavy metals due to increased contamination from environmental pollution and the existence of these metals in industrial unused products. Therefore, livestock can be exposed to heavy metal toxicity in their feeds. Because of this contamination, the quality of both goat milk and meat are greatly diminished, which causes a danger to human health (Zahrana & Hendy, 2015).

Major Heavy Metals Reported in Goats in Pakistan

The toxic and essential heavy metals were reported in different goat tissues in several studies carried out in various parts of Pakistan . One of the toxic metals that are frequently detected in goats in Pakistan is lead. Surveys carried out in Quetta have indicated that lead contaminated goat liver, kidney and meat samples collected in slaughterhouses and butcher shops. The findings revealed that liver tissues had more bioaccumulation of lead as compared to kidney and muscle tissues (Mushtaq et al., 2024). In other studies, conducted in District Swat showed the highest amount of lead found in goat's kidneys (Ikram et al., 2025)

One other major heavy metal is cadmium, research conducted in District Swat showed the highest amount of cadmium found in kidneys of goat (Ikram et al., 2025). Similarly, in Kohat reported the highest concentration of cadmium which is 1.588mg/kg (Abdel-Salam et al., 2013).

Amongst the most lethal heavy metals that are found in goats in Pakistan is mercury. A test on goat meat, liver, and kidney samples taken in Quetta slaughterhouses and butcher shops showed that the sample contained mercury. These findings revealed that the liver tissues exhibited the supreme concentration of mercury in comparison to kidney and muscle tissues. Certain samples were above the acceptable levels, which means that they were dangerous to the health of the consumers (Mushtaq et al., 2024).

According to studies conducted in different cities of Pakistan Arsenic is another major heavy metal found in in goat liver. Determination of arsenic in liver tissues which proved the contamination of visceral organs (Shah et al., 2024). Arsenic builds up in animal organs. Major target organs include liver and kidney. In the case of chronic exposure, there is damage and toxicity to the organs (Iqbal & Ashraf, 2022).

Another heavy metal has been investigated in mutton samples is nickel due to large-scale industrial activity, particularly, leather tanning activity. The tested samples contained nickel ranges from 0.41±0.580 to 3.00±0.707 mg/L levels that surpassed the international safety standards (Zahara et al., 2025).

Another heavy metal that is usually found in goats in Pakistan is chromium. In Kasur district the tested sample contained (0.885±1.252 to 5.525±2.157 mg/L) of chromium. Goats in industrial areas have been reported to accumulate Cr in their visceral organs (Zahara et al., 2025). The pollution of chromium is primarily linked to leather tanning plants, textile processing plants and metal-making plants. It was revealed that liver tissues contain more chromium than other organs (Mushtaq et al., 2024).

Copper is found more in rump muscles and liver of goats according to the studies conducted in different parts of Pakistan (Abdel- Salam et al., 2013). Generally, liver and kidney were found to have the uppermost significant levels of metals and goat meat the lowermost levels in Pakistan.

Contamination Sources of Heavy Metals

Sources are mainly in the form of environmental pollution, industrial activities, contaminated fodder and waste water irrigation as given in fig 01. In a study found in Kasur, contamination of chromium and nickel in the mutton samples was reported, and the results were attributed to industrial contamination by leather tanning manufacturing and contaminated grazing fields (Zahara et al., 2025). Equally, a study in Quetta found different heavy metals in goat meat indicating long-term contact to polluted feed,

urban contamination and industrial discharges (Mushtaq et al., 2024). Moreover, research that has been undertaken in Pakistan has shown that wastewater irrigated into soil and fodder is transferred to livestock tissues such as goat meat (Murtaza et al., 2022). A different study found nickel contamination in mutton samples, which showed that environmental exposure and feed contamination are the most significant sources of heavy metals in goat meat (Khan et al., 2025). Heavy metals are found in natural sources, like Volcanic outburst, sea salt spring, tectonic and hydro-thermal actions, dust storm, venting of rocks or microbial formation. Sources of heavy metals to people include Mining, Tanning, and fabric dyeing, battery production, insecticides and manures (Koyama et al., 2024).

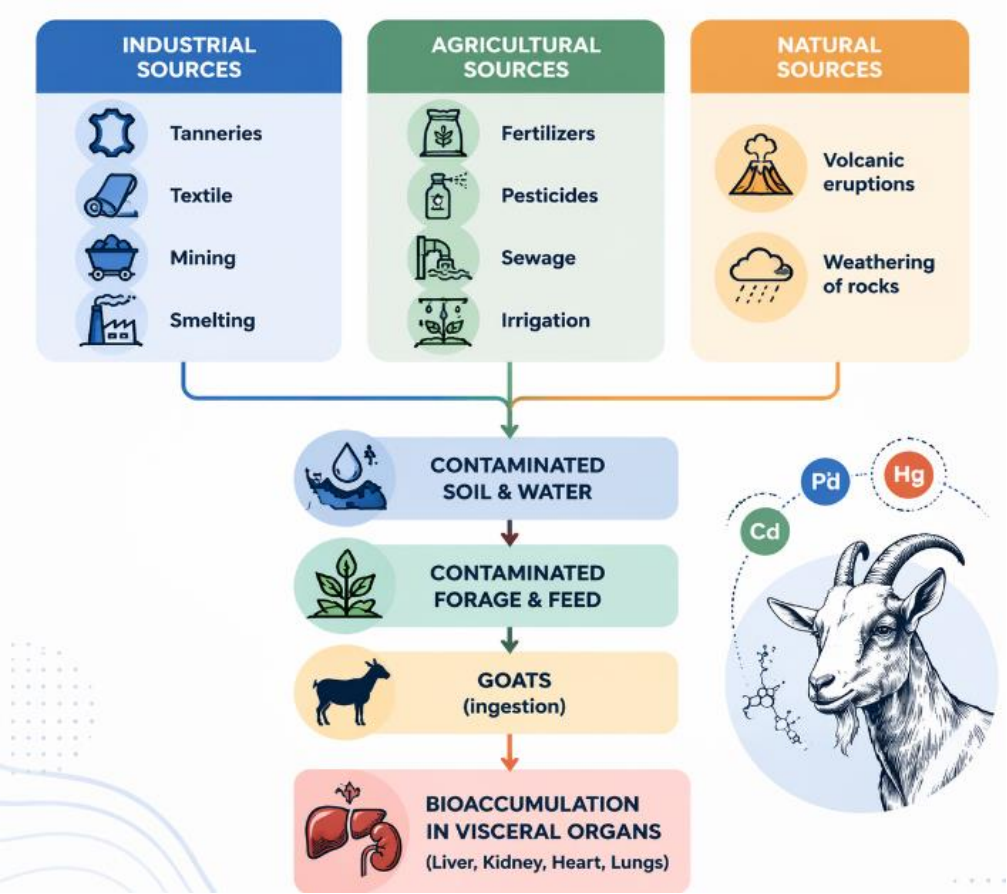

Fig. 01. Sources of heavy metals in goats

Exposure Pathways of Heavy Metals in Goats

Heavy metals gain access into the body by Gastrointestinal tract, skin or by breathing as shown in figure 2 (Guerra et al., 2012). The term environmental contamination is used to describe soil or ground water that are the recurrent routes of accessing heavy metals (Witkowska et al., 2021). Domestic animals also reside the same atmosphere as humans and are also susceptible to heavy metals sometimes due to the contaminated air they breathe in. In animals, higher concentration of heavy metal such as Pb and As have been detected in the animal fodders that may be one of the primary source of these heavy metal contamination (Tahir & Alkheraije, 2023).

The food chain receives contaminants of heavy metals in agriculture and industries (Tunegová et al., 2016). These are substances, which are highly likely to be acutely toxic. Land toxic metals have the potential to compromise plants since they are

toxic metals and will build up in the plants and when livestock like goats eat those plants heavy metals enter in their bodies (Pouresmaieli et al., 2022). The susceptibility of goats to poisonous metals is influenced by many aspects, one of which is possibly the combination of what is obligatory and what is harmful (Tahir & Alkheraije, 2023). Although some heavy metals are essential, they still all show their toxic effects by interfering with metabolism and causing alterations in body of organisms like goats. Pb and Hg cause severe toxicity in all organisms. The harmful effects of heavy metals on body will rest on the organ(s) the heavy metals are found within. As heavy metals continue to increase in the environment, those metals enter into the biogeochemical cycle and result in toxic effects on the health of all animals including goats if they drink that contaminated water (Pandey & Madhuri, 2014).

Heavy metals are the high ecological pollutant, mainly where anthropogenic stress is sky-scraping. Acquaintance to heavy metals through breathing and through consumption is the most significant route of contact in animals (Ahmad et al., 2013). The primary cause of the buildup of heavy metal in animal tissues is the period of contact. The change in enzyme concentrations is an indirect pointer of tissue injury (Iqbal & Ashraf, 2022).

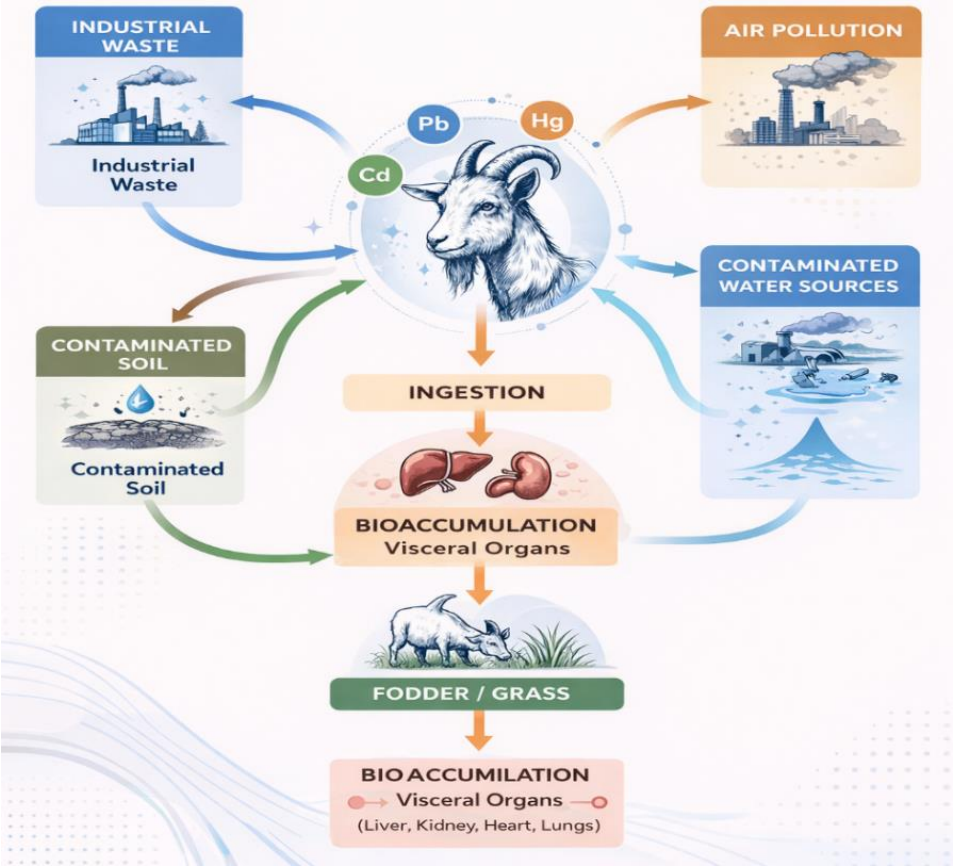

Fig.02. Exposure routes of heavy metals in goats

Bioaccumulation of the Heavy Metals in Goats

Mechanism of absorption of the pollutant by the living organisms may be by direct contact with the polluted media or indirectly by consumption of food containing the pollutant (Sunderland et al., 2010). Bioaccumulation is a situation whereby the rate of acculturation of the pollutant exceeds the rate of elimination. This causes the pollutant to be retained in the organism and build up (Chojnacka, 2010). Bioaccumulation of heavy metals has 2 stages. The metal ions are bound to the cell surface in the first stage. It is an inactive

phase of metabolism. Then metal ions are transported into the cell. Second stage is only attainable when cells are metabolically active. The biomass amount is more, when the second stage is under the optimal conditions of the organism growth. This allows more important quantities of metal ions to be bound (Nnaji et al., 2023).

Goat meat is becoming more and more significant in human nutrition because of its healthfulness and delicious flavor. It is characterized by good digestion and nutritional value. It is also quite rich in minerals (Niedziolka et al., 2009). But because of heavy metals harmfulness, its bioaccumulation and bio-magnification in the food chain, goat meat contamination and then consumption poses a significant risk (Abdel-Salam et al., 2013).

According to study research revealed that the liver and kidney are major organs in goats where the toxic heavy metals get accumulate (Gebeyew et al., 2022).

Effects on Visceral Organs of Goat

All heavy metals by being consumed in amounts beyond the tolerance level are toxic, regardless of their biological functions. The exposure of animals to heavy metals is through contaminated food, feedstuff, forage and water primarily through anthropogenic environmental pollution shown in figure 3. In some geographic locations, soils and water-bodies were observed to contain undue amount of heavy metals, which can be a natural cause of poisoning in animals (Gupta et al., 2021).

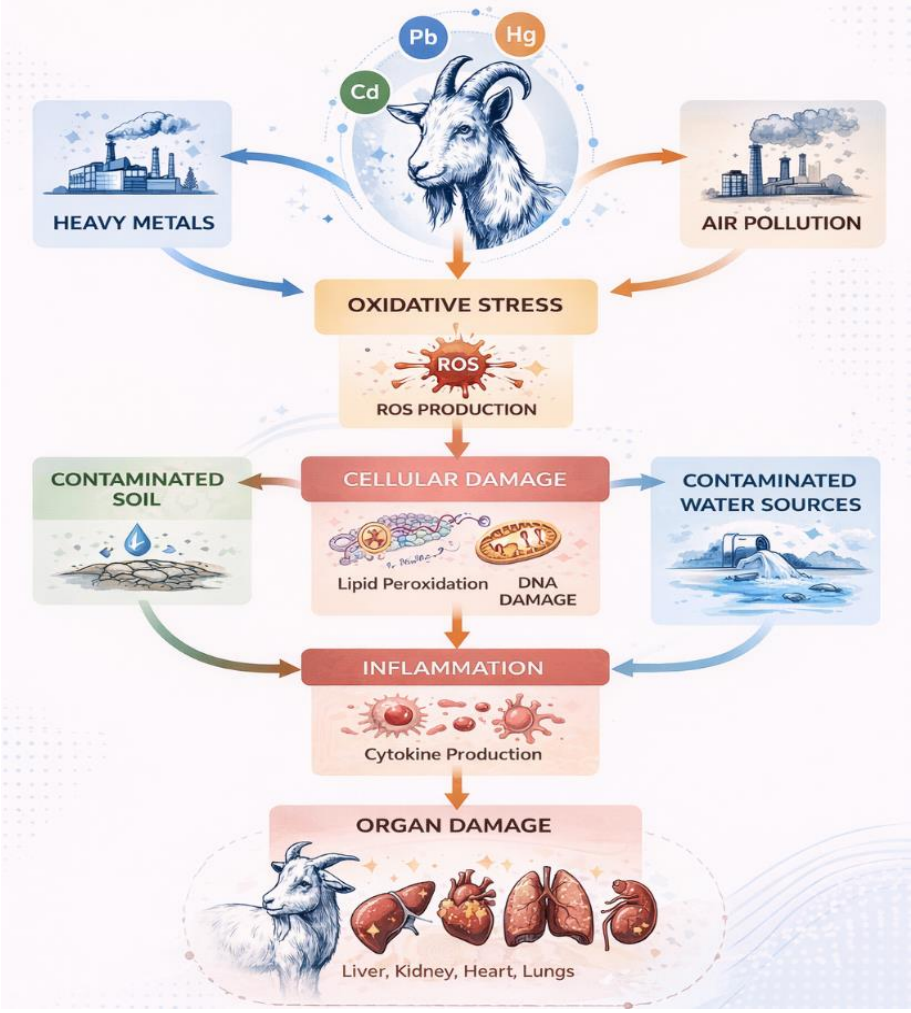

Fig.03. Toxicity mechanism of heavy metals in goats

Lead a widespread pollutant of the environment. It gets into the body of the animal through indirect sources. It gets accumulated in the different tissues of goat (Verma et al., 2018). Infected goats are likely to show signs of malnutrition, aberrant development of the fetus, opaque hair and moderate anemia and thickening of Phalange Epiphyses. Also, based on other research, Pb-poisoned animals are characterized by acute depression, muscle tremor, spasm, blackout, hepatic degeneration, death and respiratory catastrophe (Tahir & Alkheraije, 2023).

Exposure to lead in goats was found to cause oxidative stress in erythrocytes, which is an inhibited activity of antioxidant enzymes and an increased peroxidation of lipids and cellular damage through free radicals (Mousa et al., 2002). High levels of lead in goats caused oxidative stress due to depletion of antioxidant enzymes. White blood cell count and biochemical alterations were also effects of lead exposure. These results show that lead toxicity affects the liver by compromising metabolic balance, liver functions negatively and adversely affect the health of goats in general (Gioushy et al., 2025).

Exposure to cadmium results in substantial liver damage as evidenced by elevated liver enzymes like ALT and AST, that are indicators of liver damage. Cadmium was also found to cause oxidative stress in liver tissues, and interfere with normal metabolic pathways such as amino acid, lipid and energy metabolism. Metabolomics analysis also found that it cause changes in a number of metabolites related to inflammation and cellular damages (Li & Shen, 2023). Cadmium exposure produced serious damage to the spleen due to oxidative stress and increased programmed cell death in splenic tissues. It results in a breakdown of normal immunological function through damage to lymphocytes and by changing the normal structure of the spleen (Gu et al., 2015). Ceruloplasmin levels and gene expression in goats are affected by cadmium exposure, especially under molybdenum stress. It impacts how ceruloplasmin mRNAs were expressed in goat tissues; which reveals that cadmium is causing genetic level interference in ceruloplasmin. Overall, cadmium toxicity causes disturbances to both organ function and molecular & enzymatic antioxidant systems that may make goats less able to cope with oxidative stress (Zhuang et al., 2016).

Mercury is among the utmost deadly heavy metals that influence the visceral organs of the goats. It is mainly found in the kidney and liver where it induces cellular deterioration, oxidative strain, and tissue deterioration. Even low-level chronic exposure mercury binds with sulfhydryl groups of proteins, resulting in the disruption of enzyme activity, hepatic disfunction and renal failure in ruminants. Mercury has no biological advantage and even low-level chronic exposure can cause bioaccumulation in visceral organs, especially in animals grazing near industrial areas or mining zones (Nogara et al., 2024). Mercury is reported to be very toxic to kidney, liver, brain and lungs. It obstructing cellular metabolism, and leading to cellular disintegration, swelling, and necrosis. The most affected is the kidney then liver (Neathery & Miller, 1975).

Peak concentration of arsenic found in kidney and liver, then spleen, lungs and muscles. Systemic toxicity was also confirmed by the occurrence of oxidative stress, anemia, decreased body weight, and biochemical changes due to chronic contact. Arsenic leads to serious toxic effects in visceral organs of goats, especially liver and kidney, and extensive tissue collapse and bioaccumulation (Biswas et al., 2000). It states that following exposure, arsenic gets taken up and is distributed throughout the body, with its major concentration in liver, kidney, spleen, lungs, and gastrointestinal tissues. Arsenic causes hepatic disintegration, hepatocellular necrosis and fatty changes, renal tubular degeneration, glomerular injury and loss of filtration and result in dose- and duration-dependent tissue damage and progressive organ dysfunction and bioaccumulation with chronic exposure (Zubair & Martyniuk, 2019).

Moderate yet clear toxicity at the level of visceral organs was observed in goats exposed to nickel, predominantly liver and kidney. Nickel was deposited in these organs and caused mild to moderate hepatocellular disintegration, sinusoidal congestion and fatty liver changes at times. The toxicity of nickel was reported to be less severe than cadmium and lead (Shukla, 2019). Ni is an

increasing environmental pollutant caused by industrial wastes, polluted soils, water and food exposure of goats to nickel may cause hepatic stress that includes subtle degeneration of hepatocytes, liver enzyme activity, and oxidative stress. Nickel is linked to irritation of the tubular epithelia and early degeneration of the kidney and low renal performance in the kidney of chronic exposure (Shukla et al., 2020).

In general, normal dietary chromium supplementation is safe and effective, but that high environmental exposure can result in toxic buildup in internal organs of ruminants, which can potentially cause oxidative stress, tissue damage and impaired organ functions. The toxicity is more related to hexavalent chromium that is more detrimental than trivalent chromium that is widely applied in feed supplements (Zarczynska & Krzebietke, 2020). Goats that fed unbalanced chromium had slight yet significant visceral organ changes. Liver demonstrates slight deteriorating alterations and metabolic stresses. There are acinous irregularity and structural change of pancreas. There was a change in the biochemical pointers of liver functioning in some of the animals. Chromium do not cause serious lesions as Cd or Pb, however, mineral balance disruption may impact liver and digestive organs (Aupperle et al., 2001).

Factors Affecting Heavy Metal Accumulation in Goats

The combined action of ecological, biological and physiological aspects determines the rate of heavy metal in goats. It has been found that the main causes of exposure include environmental pollution of manufacturing and mining activities which in turn causes accumulation via the soil-plant-goat continuum (Li et al., 2025).

The age of a goat also has a major impact as it is always demonstrated that old goats have a high concentration of metals in their tissues because of bioaccumulation with age (Kar et al., 2015). Heavy metal accumulation in old goats is higher as compared to young goats. In a study of Angora goats, it was discovered that the adult goats contained much more heavy metals than the young goats. There were also enhanced lipid peroxidation and reduced antioxidant vitamins in older animals (Simsek et al., 2015). The age-related changes in milk samples indicated that, as age advanced, the levels of cadmium, copper, chromium, and manganese rose in goats whereas, zinc and iron are on downward trends (Batool et al., 2026). This process is also influenced by physiological status; an example of this is that pregnant goats have been reported to have elevated blood lead levels than lactating goats (Pareja-Carrera et al., 2024). The plasma cobalt levels were found to be higher in male goats than in other groups, and fecal cobalt levels were higher in lactating goats than in other classes (Khan et al., 2003). pH and organic matter levels in soil influence the availability of metals. Acidic soils enhance solubility and uptake of metals by plants. In the mining regions, plants exhibited Bioconcentration factors in the soil of 0.840-5.30 of soil Mo meaning that it is efficiently transferred to the vegetation that goats fed on (Li et al., 2025). Goats raised around mining fields, industrial sectors, or petroleum fields amass much greater amounts of metals. A molybdenum mining area reported higher molybdenum levels in the hair samples in goats compared to urban and rural areas (Li et al., 2025). Likewise, goats in the area of petroleum industries exhibited elevated concentrations of nickel, lead, and vanadium in milk, blood, muscle, liver and kidney (Ajarem et al., 2023). Polluted water and supplement feed also play a main role in the intake of metals. The addition of feed and water assisted in sustaining sufficient cobalt levels in goats even though forage levels were low (Khan et al., 2003). Metal connections play a serious role in accumulation. Copper and molybdenum antagonize in vivo; thus, Mo fertilization may decrease Cu absorption in goats (Li et al., 2022).

Research Gaps

Only 4-7 organs have been studied; liver/kidney accumulate more than muscles, yet there are few studies of goat multi-organs in Pakistan (Sharaf et al., 2021). All found studies are cross-sectional (single time point). No study monitor heavy metals in the same animal populations over months/years (Khan et al., 2024). Study was

focused in Lahore and some districts in Punjab. No Sindh, KP, Gilgit-Baltistan or Azad Kashmir data. Also missing national safety standards (Jamil et al., 2015). Systematic monitoring program is very essential in Pakistan. A market survey in Lahore has specifically indicated that without the national safety standards being in place with regard to the content of heavy metals in feed, the obtained outcomes were compared to the international standards and found to be significantly higher than the suggested safe limit of the heavy metals in foodstuffs. This underscores the dire necessity of the development of national safety standards of heavy metals in food, Periodic monitoring of commercially sold meat products, livestock water and feed monitoring and monitoring to all provinces. The protection of health of the population requires extensive risk evaluation studies (Jamil et al., 2015).

Conclusion

This review shows that in several areas of Pakistan goat visceral organs are commonly contaminated with harmful amounts of toxic and heavy metals. The kidney and liver are the two tissues that will always have the greatest metal loads leading to reported tissue damage such as cell degeneration, necrosis and impairment of functional activity of the two important organs. Whenever the human being eats these contaminated tissues, they are at a tremendous health risk; existing reports show that the estimates of daily intake of chromium and mercury already exceed the established safety limits of adult human beings. Although this situation is very serious, there are still serious information gaps. They comprise absence of measurements across time, limited studies between different types of organs as well as limited data on large sections of the country other than Punjab and small parts of Baluchistan. Also, Pakistan has not yet implemented official maximum allowable concentration of heavy metals in edible animal products which means that the consumer has no regulatory protection. The urgent step should be taken to introduce regular testing programs at the national level with the use of modern analytical tools and comprehensive risk assessment models. It is also important to set up enforceable standards in food safety as well as informing the people on the risks of eating liver and kidney tissues of goats that have been reared in contaminated areas. By combining efforts in research, enhanced regulations, and clean-up of the environment, Pakistan can minimize health hazards of contaminating heavy metal in goat meat supply, in the long run.

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