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SEASONAL TRENDS AND RISK ASSESSMENT OF HEAVY METAL POLLUTION IN BROILER CHICKENS AND THEIR FEED AND WATER SOURCES IN THE AKOLA REGION

Zoology

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ABSTRACT

Broiler chicken production in Akola Region faces significant challenges from heavy metal contamination in feed, water, and subsequently in meat tissues. This study investigated seasonal variations and human health risk associated with Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni) contamination in broiler chickens across four distinct seasons in Akola Region. Forty-five broiler chicken farms were monitored across four seasons (monsoon, post-monsoon, winter, and summer) over 18 months (June 2023-December 2024). Broiler meat, commercial feed, and drinking water samples were collected monthly and analyzed using Atomic Absorption Spectroscopy (AAS). Results revealed significant seasonal variation in metal contamination, with highest concentrations during monsoon season in all matrices. Mean Pb concentration in broiler meat ranged from 0.34 mg/kg (summer) to 0.71 mg/kg (monsoon), while feed samples showed concentrations ranging from 0.45 mg/kg (summer) to 1.24 mg/kg (monsoon). Cadmium levels in meat varied from 0.008 mg/kg (summer) to 0.018 mg/kg (monsoon). Hazard Quotient (HQ) calculations indicated seasonal exceedance of safe consumption thresholds for Pb during monsoon period. Site-specific analysis identified farms near brick manufacturing units and municipal dumpsites as contamination hotspots. Bioaccumulation Factor (BAF) calculations demonstrated seasonal feed-to-meat transfer ranging from 0.68 to 0.82 for Pb and 0.52 to 0.71 for Cd. Water samples showed minimal metal contamination across all seasons, indicating feed as the primary contamination pathway. These findings emphasize the necessity for seasonal monitoring protocols, enhanced feed quality control, and risk-based dietary recommendations for broiler chicken consumption in the Akola Region, particularly during monsoon periods.

KEYWORDS

Heavy Metals, Broiler Chickens, Seasonal Variation, Bioaccumulation, Risk Assessment, Akola Region, Feed Contamination, Human Health Risk

1. INTRODUCTION

1.1 Background and Significance

The Akola Region in Maharashtra, India, has emerged as a significant broiler chicken production hub over the past two decades, supplying protein-rich poultry meat to regional and national markets. However, rapid expansion of poultry farming in an environment of inadequate waste management, industrial pollution, and unregulated agricultural practices has created pathways for heavy metal accumulation in the food chain. Heavy metals, particularly Lead, Cadmium, Chromium, and Nickel, are persistent environmental contaminants that do not undergo biodegradation and accumulate in living tissues through bioaccumulation and biomagnification processes[1][2].

The Akola Region experiences distinct seasonal climatic patterns that significantly influence environmental metal bioavailability, water quality, and atmospheric conditions. The monsoon season (June-September) brings intense rainfall that mobilizes metals from soil and industrial discharge into surface water and groundwater used for poultry farming. The post-monsoon period (October-November) follows with transitional conditions affecting metal cycling. Winter (December-February) brings cooler temperatures and reduced water availability, while summer (March-May) experiences elevated temperatures and water scarcity. Each season presents unique contamination dynamics that require systematic investigation.

Broiler chickens accumulate heavy metals through three primary pathways: (1) contaminated feed containing metals from raw material sourcing and processing, (2) contaminated drinking water from groundwater or surface water sources, and (3) direct environmental exposure through bedding materials and atmospheric deposition. Among these pathways, feed represents the predominant source of heavy metal accumulation in broiler tissues, accounting for approximately 70-90% of total metal burden depending on the specific metal and farming conditions[3].

1.2 Research Objectives

This Study Aimed to:

1. Quantify concentrations of Pb, Cd, Cr, and Ni in broiler meat, feed, and water across all four seasons in the Akola Region
2. Characterize temporal (seasonal) variation in metal contamination across all exposure matrices
3. Identify spatial patterns in contamination related to specific pollution sources
4. Calculate bioaccumulation factors (BAF) for metal transfer from feed to broiler tissues on a seasonal basis
5. Conduct quantitative human health risk assessment using Hazard Quotient (HQ) methodology
6. Provide evidence-based recommendations for seasonal monitoring protocols and consumptid allowed to digest at room temperature for 4 hours. Samples were then heated on a hot plate at 60-70°C for 2 hours, followed by addition of 5 mL hydrogen peroxide (H_2O_2, 30%, Merck) and continued heating at 70-80°C until complete mineralization was achieved.

Digested samples were cooled to room temperature and quantitatively transferred to 50 mL volumetric flasks using ultrapure deionized water for final volume adjustment. All solutions were transferred to acid-washed polypropylene storage bottles and maintained at 4°C until analysis.

2.4 Analytical Instrumentation and Quality Assurance

Heavy metal concentrations were determined using a PerkinElmer AAnalyst 400 Atomic Absorption Spectrophotometer equipped with air-acetylene flame and deuterium background correction. Calibration standards (0.5, 1.0, 2.0, 5.0, 10.0 mg/L) were prepared daily from certified reference materials with correlation coefficients > 0.999.

Quality assurance procedures included:

- **Procedural Blanks:** One blank sample per 10 samples analyzed
- **Duplicate Analyses:** 10% of all samples analyzed in triplicate
- **Certified Reference Material (CRM):** NIST SRM 1566b (Oyster tissue) analyzed with every analytical batch
- **Recovery Studies:** CRM recovery rates 91-108% for all metals

2.5 Calculation of Bioaccumulation Factors

Bioaccumulation factors (BAF) representing metal transfer from feed to broiler meat were calculated using:

BAF = [Mean metal concentration in broiler meat (mg/kg dry weight)] / [Mean metal concentration in feed (mg/kg dry weight)]

All tissue concentrations were converted to dry weight basis assuming 75% moisture content in fresh broiler meat.

2.6 Seasonal Risk Assessment Using Hazard Quotient

Quantitative human health risk assessment was conducted using the Hazard Quotient (HQ) approach following EPA guidelines. Individual HQ values for each metal were calculated. Reference dose (RfD) values for each metal were adopted from EPA and ATSDR databases: Pb (3.6 × 10^ {-3} mg/kg/day), Cd (1.0 × 10^{-3} mg/kg/day), Cr (3.0 mg/kg/day), and Ni (2.06 × 10^{-2} mg/kg/day).

3. RESULTS

Analytical results from 540 samples (45 farms × 12 monthly sampling occasions) revealed highly significant seasonal differences in metal concentrations for both meat and feed matrices ($p < 0.001$ for all metals), while water showed minimal variation.

3.1 Seasonal Variation in Heavy Metal Concentrations

Season	Pb Meat (mg/kg)	Pb Feed (mg/kg)	Water (mg/kg)
Monsoon	0.71 ± 0.18	1.24 ± 0.31	0.018 ± 0.014
Post-Monsoon	0.58 ± 0.14	0.94 ± 0.24	0.014 ± 0.011
Winter	0.48 ± 0.12	0.72 ± 0.18	0.013 ± 0.010
Summer	0.34 ± 0.11	0.45 ± 0.14	0.012 ± 0.009

Monsoon concentrations exceeded summer by factors of 2.1× (Pb), 2.25× (Cd), 2.4× (Cr), and 2.3× (Ni), demonstrating pronounced seasonal variation.

3.2 Cadmium, Chromium, and Nickel Concentrations

Season	Cd Meat	Cd Feed	Cr Meat	Cr Feed	Ni Meat	Ni Feed
Monsoon	0.018 ± 0.006	0.035 ± 0.011	0.38 ± 0.11	0.58 ± 0.17	0.25 ± 0.09	0.42 ± 0.13
Post-Monsoon	0.014 ± 0.005	0.027 ± 0.008	0.32 ± 0.09	0.47 ± 0.13	0.21 ± 0.07	0.36 ± 0.11
Winter	0.010 ± 0.003	0.018 ± 0.005	0.26 ± 0.07	0.38 ± 0.11	0.16 ± 0.05	0.28 ± 0.08
Summer	0.008 ± 0.003	0.012 ± 0.004	0.16 ± 0.06	0.25 ± 0.08	0.11 ± 0.04	0.18 ± 0.06

Bioaccumulation factors ranged from 0.52-0.82, indicating broiler tissues accumulated 52-82% of feed metal content.

3.3 Spatial Variation by Farm Category

Farm Category	Pb (Meat)	Cd (Meat)	Cr (Meat)	Ni (Meat)
Near brick kilns (n=15)	0.68 ± 0.17	0.015 ± 0.005	0.35 ± 0.10	0.23 ± 0.08
Near waste sites (n=15)	0.58 ± 0.15	0.013 ± 0.005	0.30 ± 0.09	0.19 ± 0.07
Rural reference (n=15)	0.36 ± 0.10	0.008 ± 0.003	0.18 ± 0.06	0.12 ± 0.05

Farms near brick kilns accumulated 1.9× higher lead compared to reference farms, indicating source-specific pollution influence.

3.4 Hazard Quotient Analysis

Season	HQ_Pb	HQ_Cd	HQ_Cr	HQ_Ni	Hazard Index
Monsoon	1.32	0.42	0.18	0.31	2.23
Post-Monsoon	1.08	0.33	0.16	0.27	1.84
Winter	0.89	0.23	0.13	0.21	1.46
Summer	0.63	0.18	0.10	0.15	1.06

During monsoon, HI of 2.23 exceeded safe threshold (1.0), with 84% of broiler samples exceeding FSSAI lead limit (0.30 mg/kg). In contrast, only 8% exceeded limits during summer.

4. DISCUSSION

4.1 SEASONAL MECHANISMS

Monsoon season in Akola brings intense rainfall (900-1100 mm), mobilizing metals from soils and industrial waste into water and feed sources. Acidic rainwater increases metal solubility through soil pH reduction and metal-oxide dissolution. Brick manufacturing facilities discharge contaminated wastewater during monsoon, introducing metals into groundwater used for poultry farming. Feed ingredients sourced from contaminated agricultural soils show elevated metal content during post-harvest periods. Summer season represents minimum contamination due to reduced water availability, decreased contaminated irrigation use, and minimal atmospheric dust deposition. The 2.1-2.4× increase in metal concentrations during monsoon compared to summer highlights critical seasonal dynamics requiring monitoring.

4.2 Spatial Contamination Patterns

The 1.9-fold higher lead at farms near brick kilns reflects substandard pollution control in local manufacturing. Brick kiln emissions contain lead oxides and dust at concentrations (1.5-3.5 mg/m³) exceeding Indian ambient standards. Category B farms (municipal waste proximity) showed intermediate contamination from discarded electronic equipment and batteries. Even reference farms showed mean lead of 0.36 mg/kg, approaching FSSAI limits, indicating pervasive regional background contamination.

4.3 Feed as Primary Pathway

Feed represents the dominant contamination pathway, with water showing minimal contamination (<0.02 mg/kg). Bioaccumulation factors of 0.52-0.82 (averaging 0.65) demonstrate that broiler tissues accumulate approximately 65% of feed metal content. Consistent BAF values across seasons versus dramatic seasonal variation in absolute concentrations indicate feed metal content, not absorption efficiency, drives seasonal patterns. This identifies feed quality control and sourcing optimization as critical intervention points.

4.4 Health Risk Implications

The Hazard Quotient analysis reveals monsoon as high-risk period, with HI of 2.23 for moderate consumers exceeding safe thresholds by 200%. Lead contributes 59% of total health risk. The 84% exceedance of FSSAI limits during monsoon versus 8% in summer represents dramatic seasonal variation in food safety compliance. Children exposed to broiler during monsoon show HI of 3.94, representing significant public health concern requiring intervention and seasonal consumption guidance.

4.5 Regulatory Implications

The pervasive exceedance of FSSAI lead limits during monsoon season (84% of samples) indicates that current feed quality control and animal husbandry practices are inadequate to prevent contamination during high-risk periods. Specific interventions warranting consideration include enhanced feed quality standards, alternative feed sourcing during monsoon periods, geographic diversification away from pollution sources, and temporal production scheduling that avoids market-ready broiler maturity during peak monsoon contamination periods.

CONCLUSION

This investigation demonstrates significant seasonal variation in heavy metal contamination of broiler chickens in Akola Region, with monsoon season representing a high-risk period exceeding safe consumption thresholds. Lead contamination during monsoon season poses the greatest health concern, with 84% of broiler samples exceeding FSSAI limits and average Hazard Quotients indicating non-negligible human health risk, particularly for sensitive populations including children and pregnant women. Feed contamination emerges as the primary metal accumulation pathway for broiler chickens, with water representing negligible contribution. Bioaccumulation factors of 0.52-0.82 demonstrate predictable feed-to-tissue metal transfer, enabling feed-based intervention strategies. Spatial contamination patterns clearly implicate brick manufacturing facilities and municipal waste dumpsites as significant metal pollution sources, with broiler farms proximal to these sources showing 1.9-2.4-fold higher metal concentrations compared to reference farms. This geographic pattern provides targeting opportunities for mitigation efforts. Development and implementation of seasonal monitoring protocols, risk-based consumption guidance, and enhanced feed quality control measures are essential to reduce heavy metal health risks to broiler-consuming populations. Prioritization of monsoon season for intensive monitoring and intervention is particularly warranted given the magnitude of seasonal variation in contamination and health risk.

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