



Research Article

A One Health Approach to the Farm to Slaughter Continuum: Comparative Risk Assessment Index (CRAI) Analysis of Farm Management and Slaughterhouse Practices Affecting Cattle Health and Meat Safety in Karachi, Pakistan

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Abstract | This research assesses the integrated effects of farm management and slaughterhouse practices on cattle health and meat safety through a One Health approach in Karachi. A Comparative Risk Assessment Index (CRAI) was constructed to consider important variables along the livestock value chain, such as farm management, biosecurity, sanitation and waste management, feed and water safety, veterinary services and slaughterhouse hygiene. Surveys, observations and interviews were conducted in various districts, with data analysed using descriptive statistics and chi-square tests. The findings indicated a high degree of spatial variability in risk, with CRAI scores ranging from 3.00 to 4.67 in different districts. East district was the riskiest (4.67) followed by Central (4.00), suggesting weak integration of slaughter and farm management practices. Korangi (3.00) and Malir (3.33) districts had moderate risk, largely attributed to lack of sanitation, biosecurity, and veterinary services. The major risk factors at the farm level were poor waste disposal (32%), absence of animal isolation, poor animal movements, and vaccination, leading to disease spread. At the slaughterhouse level, poor practice in waste disposal (38%), hygiene (35%) and poor infrastructure (lack of cold storage, poor drainage) were identified as critical. The results show that risk factors for meat safety are additive, involving the whole of the farm-to-slaughter life cycle. The CRAI model nicely captures these effects and shows that reducing risk in one stage does not reduce the risk. The research highlights the need for holistic approaches in a One Health approach, focusing on farm biosecurity, waste disposal, veterinary services, and slaughterhouse facilities and inspections. Overall, the CRAI represents a practical and scalable risk assessment model for urban livestock systems, which can inform evidence-based policy and decision-making to enhance animal health, meat safety and human health.

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Introduction

Livestock sector is a critical part of Pakistan's Agricultural economy, playing a vital role in food security, rural incomes and economic growth. It plays a major role in value addition and is a lifeblood for millions of households in milk and meat production. Pakistan has one of the world's largest herds of cattle and buffaloes, with more than 90 million animals, underscoring the sector's critical role in meeting nutritional needs and generating income (Afzal and Naqvi, 2004). Over the past few decades, urbanization has changed livestock production systems, especially in major urban centres such as Karachi where urban and peri-urban livestock production has grown to cater for the growing demand of fresh dairy and meat products.

Pakistan's largest metropolis and economic centre, Karachi, is home to a multifaceted livestock production system, featuring densely populated dairy colonies, informal livestock farming, and constant rural-urban migration of animals. Livestock hubs such as Landhi (Bhains colony), Malir and Korangi play a vital role in supplying milk and meat to the urban population. But these systems face numerous challenges, such as high stocking density, limited shelter, poor hygiene and lack of veterinary care. These factors provide a suitable environment for disease outbreaks and lower livestock productivity (Agribusiness Support Fund, 2013; Hussain *et al.*, 2019).

Disease prevalence is a significant issue in cattle health in Pakistan. Diseases like Lumpy Skin Disease (LSD), Foot and Mouth Disease (FMD), brucellosis and bovine tuberculosis (bTB) are highly prevalent and have significant economic and health impacts. LSD, for example, has become a major transboundary disease in recent years, with rapid spread attributed to the presence of vectors, weather conditions and the lack of vaccination efforts (Sadiq *et al.*, 2023). Likewise, FMD is endemic in Pakistan and is often linked to animal transportation and inadequate biosecurity practices. Chronic zoonotic diseases like brucellosis and bovine tuberculosis also impact animal productivity, and it's a risk to human health, especially for those who are involved in livestock and meat processing (Fatima *et al.*, 2008).

Disease persistence and spread is strongly related to farm management. In urban and peri-urban livestock

production systems, farmers may practice traditional management, which includes sub-optimal feeding, hygiene, quarantine and disease surveillance. These methods compromise the immune response in animals and promote disease transmission within and among herds. Additionally, the lack of systematic vaccination and farmer knowledge about disease prevention practices are responsible for sustaining endemic disease states (Hussain *et al.*, 2019; Agribusiness Support Fund, 2013). Other environmental factors, including waste mismanagement, stagnant water, and vectors, add to the spread of diseases in high-density livestock production systems.

While the health of animals at farm level sets the foundation for meat safety, slaughterhouses are key points in the livestock value chain where meat safety is maintained or jeopardized. Slaughterhouse practices, such as ante-mortem and post-mortem inspections, carcass management and waste management, are critical in ensuring that unsafe meat does not reach consumers. Karachi has formal slaughterhouses that are regulated by the municipal government; however, there are differences in hygiene practices, infrastructure and efficiency. Research has identified shortcomings in sanitation measures, waste disposal systems, and training for workers, which can lead to higher risks of microbial contamination and food poisoning (Soomro *et al.*, 2021; World Bank, 2022).

One health is a global concept that promotes an integrated approach to animal, human and environmental health. In livestock production, especially in rapidly urbanizing areas like Karachi, the one health concept is particularly important because of the interactions between people, animals and the environment. Livestock diseases have implications for animal productivity and zoonotic risks, particularly in the absence of good hygiene and biosecurity measures. Pathogen spread along the farm to slaughter chain suggests that a comprehensive approach to risk mitigation is required, rather than fragmented interventions (World Bank, 2022; World Health Organization, 2017).

In a one health approach, farm management and slaughterhouses are key nodes that impact food safety and human health. Substandard farm practices, including poor hygiene, waste management and veterinary services, contribute to the spread of infectious diseases such as brucellosis and bovine

tuberculosis, which can spread to humans via direct contact or contaminated animal products (Fatima *et al.*, 2008; Farooq *et al.*, 2023). Likewise, inadequate slaughterhouse practices, such as poor hygiene, improper disposal of waste and carcasses, and cross-contamination during processing, further exacerbate these risks. Research from Karachi has demonstrated that poor abattoir hygiene affects the safety of meat, stressing the need for integrated monitoring programs (Soomro *et al.*, 2021).

The environment is a critical element of one health in urban livestock systems, where inadequate handling of animal waste and carcasses can lead to environmental pollution and disease persistence. Environmental contamination can serve as a source of diseases like anthrax and other bacterial pathogens, which can then spread among livestock and potentially to humans. The concentration of livestock in peri-urban areas of Karachi compounds these risks and provides a dynamic environment in which environmental, animal and human health interact (Hussain *et al.*, 2019; Food and Agriculture Organization of the United Nations, 2013).

Although the one health concept is recognised as important, in Pakistan, most studies have examined either the prevalence of diseases on farms or the hygiene problems at slaughterhouses separately rather than collectively in an integrated model. This makes it difficult to grasp the risk transmission along the livestock value chain. So, the current study focuses on the one health approach by developing a Comparative Risk Assessment Index (CRAI) that considers farm management, biosecurity, sanitation and slaughterhouse hygiene as a composite index. This allows for a holistic evaluation of cattle health and meat safety, which will provide science-based evidence for targeted interventions and policymaking (World Organisation for Animal Health, 2021).

Crucially, cattle health and meat safety are not isolated events but are linked aspects of a “farm to slaughter” continuum. Poorly managed cattle are more likely to harbour diseases and infections during slaughter, and these risks may be compounded by poor hygiene practices in the slaughterhouse. Recent evidence from slaughterhouse-based studies in Karachi has demonstrated that livestock diseases like bovine tuberculosis are often encountered at slaughterhouses, indicating a lack of effective disease surveillance

and control on farms (Farooq *et al.*, 2023). This interdependence calls for a holistic view of livestock systems rather than focusing on farm management and slaughterhouse processes separately.

While this is a critical issue, current research in Pakistan has tended to study isolated components of livestock production, such as disease status, farm management or slaughterhouse practices, without considering the interconnections between these elements. In urban areas such as Karachi where livestock systems are complex and affect by environmental, socio-economic and institutional factors, such isolated approaches restrict interventions. A holistic approach is required to understand the relationship between farm and slaughterhouse conditions in terms of their effects on cattle health and meat safety.

Thus, the current study seeks to offer comprehensive evaluation of cattle health, farm conditions and slaughterhouses in Karachi with one health approach. By considering these factors together, the study aims to determine the major risk factors, assess their interactions, and provide evidence-based guidelines for better cattle productivity and safe meat production. The study builds on the need for integrated farm and post-slaughter assessments to inform the development of integrated approaches to livestock production and public health in the urban setting.

Materials and Methods

Study area

This study was carried out in Pakistan’s largest metropolitan and economic centre, Karachi, at the coordinates of 24°45’-25°15’ N and 66°37’-67°37’ E. The city has an area of about 3,600 km² and a semi-arid climate with hot summers, cool winters and an average annual rainfall of about 250 mm, mostly received in the monsoon months (July-September). Karachi has large urban and peri-urban livestock production systems, with dairy colonies (Landhi, Malir, Korangi and Gadap) as major sources of milk and meat. But these colonies also have dense livestock populations, frequent animal movement and risk of disease outbreaks.

Study design and duration

This study used a cross-sectional design to evaluate management practices on farms, health status of animals, and slaughterhouse hygiene. Data has been

collected for one year, enabling seasonal effects on disease and management practices to be considered. A mixed methods approach was applied in this study to incorporate both quantitative and qualitative data to better understand the livestock system. Cross-sectional studies are commonly used in epidemiological research to determine the prevalence of disease and risk factors in a population ([Thrusfield, 2018](#)).

Sampling strategy

A stratified random sampling strategy has been employed to ensure a sample from different administrative areas of Karachi. The city was divided into six strata by district:

- District Korangi
- District Malir
- District South
- District East
- District West
- District Central

The two districts were treated as strata because of differences in herd size, management, environment and disease risks.

We selected 3,500 cattle for the study, approximately 583-584 from each district. Further, 60 cattle farms were chosen for field study to ensure representation of different farm sizes, production systems, and farm management.

Stratified random sampling increases the accuracy of estimates by representation of all subpopulations of the population ([Cochran, 1977](#)).

Data collection methods

Primary data collection

Primary data were collected through:

- Weekly surveys and visits to farms
- Observations of the management of farms (housing, feeding, hygiene, biosecurity)
- Interviews with farmers, herdsman and veterinarians
- Observations of slaughterhouses

Information collected included:

- Nutrition and feeding
- Herd (density, housing)
- Sanitation and waste disposal practices
- Vaccination and diseases
- Biosecurity and animal movements

Interviews were conducted in the local languages (Urdu and Sindhi) to avoid any language barrier.

Secondary data collection

Secondary data were obtained from:

- Livestock Department Sindh
- Karachi Metropolitan Corporation
- Veterinary hospitals and clinics
- Research articles and reports

This information included outbreak reports, vaccination programs, mortality and population data.

Slaughterhouse assessment

Slaughterhouse practices were assessed by observing:

- Pre-slaughter and post-slaughter inspections
- Slaughter, skinning and evisceration
- Handling and transportation of carcasses
- Waste disposal systems
- Hygiene and sanitation of workers

These indicators were examined to determine risks of contamination and adherence to good hygiene practices. Slaughterhouses are considered critical control points in meat safety management systems, especially under the Hazard Analysis and Critical Control Point (HACCP) systems ([FAO/WHO, 2003](#)).

Disease prevalence estimation

Disease prevalence was calculated using the standard epidemiological formula:

$$\text{Disease Frequency (\%)} = \frac{\text{Number of Positive Cases}}{\text{Total Number of Animals Examined}} \times 100$$

Where; Number of positive cases = animals diagnosed with a specific disease. Total number of animals examined = 3,500.

This method is widely used for estimating prevalence in cross-sectional studies ([Thrusfield, 2018](#)).

Comparative risk assessment index (CRAI)

To evaluate the combined impact of farm-level management and slaughterhouse hygiene on cattle health and meat safety, a Comparative Risk Assessment Index (CRAI) was developed.

$$CRAI = \frac{FM + BS + SD + FS + VD}{SH}$$

Where; FM=farm management score (housing, hygiene,

herd density). BS= biosecurity score (vaccination, isolation, movement control). SD= sanitation and disposal score (waste and carcass handling). FS= feed and water safety score. VD= veterinary access score. SH= slaughterhouse hygiene score.

The CRAI provides a composite measure of risk by integrating multiple variables across the livestock value chain. Higher CRAI values indicate greater overall risk due to poor farm management and inadequate slaughterhouse hygiene.

Data analysis

Microsoft Excel was used for data organisation and analysis. The following methods were used:

- Frequency, percentage and mean calculations for summarising disease incidence and disease management
- Comparative analysis across districts to identify spatial variation
- Chi-square (χ^2) test for assessing the relationship between risk factors (e.g., practices of waste disposal) and disease

We considered $p < 0.05$ as the level of significance. This is a standard approach in epidemiological research to assess the relationship between categorical variables (Dohoo *et al.*, 2009).

Ethical considerations

The respondents and farmers were involved freely. Oral consent was sought before interviews and data was only used for research. Animal observations were conducted according to the accepted ethical guidelines.

Results

The research was carried out for a year and involved a series of field investigations of livestock farms, slaughterhouses, veterinary clinics and other ancillary facilities in Karachi. The researchers surveyed 3,500 cattle from six administrative districts for disease prevalence, farm management and slaughter practices. The results showed significant diversity in farm management, disease prevalence, and slaughterhouse conditions, pointing to the link between cattle health and meat safety in the livestock production chain.

Disease prevalence in cattle population

The prevalence study of diseases revealed mastitis

was the most prevalent (26.3%, $n = 921$), followed by anthrax (18.5%, $n = 648$) and Foot and Mouth Disease (FMD) (15.0%, $n = 525$). Lumpy Skin Disease (12.0%, $n = 420$), brucellosis (10.2%) and bovine tuberculosis (8.4%) were other prevalent diseases. Less frequent diseases included theileriosis (6.1%), pneumonia (4.37%), endoparasitosis (3.5%), Black Quarter (2.29%) and Hemorrhagic Septicemia (1.57%).

The prevalence of mastitis was highly correlated with poor milking hygiene, unhygienic milking equipment and crowded dairy sheds, as reported by Hussain *et al.* (2019). Likewise, the prevalence of anthrax was associated with environmental pollution and improper disposal of carcasses, which pose significant risks to livestock production (World Bank, 2022). The distribution of FMD and Lumpy Skin Disease shows patterns of contagious and vector-borne diseases related to animal movement and climatic factors (Sadiq *et al.*, 2023). Zoonotic diseases such as brucellosis and bovine tuberculosis were mostly found in adult cattle, suggesting a lack of surveillance and long-term control strategies (Farooq *et al.*, 2023; Fatima *et al.*, 2008).

District-wise variation in disease distribution

There was considerable spatial heterogeneity in the prevalence of disease in the six districts of Karachi. Korangi, Malir and West districts were identified as hotspots with higher prevalence of multiple diseases. Korangi (17%), West (12.4%) and Malir (10.5%) had a higher prevalence of mastitis, likely due to poor hygiene and intensive dairy farming. This observation is in line with participatory surveillance studies that indicate the impact of farm density and management on disease transmission (Hussain *et al.*, 2019).

Anthrax was also high in Malir (16%), Korangi (15.8%) and East (14.2%) districts, which could be due to persistent pathogens in the environment because of improper carcass management. The highest prevalence of Pneumonia was found in Malir (11.57%), likely due to poor ventilation and overcrowding of livestock. Likewise, Black Quarter and Hemorrhagic Septicemia prevalence was higher in Korangi and West districts, suggesting environmental and management risk factors.

By contrast, the south and central districts had lower occurrence of diseases, possibly due to smaller flock sizes and better farm management practices. These

findings are consistent with epidemiological evidence on the impacts of livestock density, environment and disease risks (World Bank, 2022).

Farm-level management and risks

Review of on-farm practices identified common problems with hygiene, biosecurity and waste management. Nearly 32% of farms (112 of 350) were identified as having poor carcass and waste disposal measures. Chi-square tests revealed a significant link between poor waste management and mastitis prevalence ($\chi^2 = 7.82$, $p < 0.05$), suggesting that poor hygiene plays a significant role in disease spread.

Table 1 offers a comparative analysis of hygiene scores and risk levels of various operational stages in slaughterhouses in Karachi. This suggests that the slaughtering area, waste handling systems and meat storage areas have low hygiene scores and high-risk levels predominantly attributed to inadequate cleaning and sanitization protocols, poor waste management and lack of refrigeration facilities. These practices enhance the chances of microbial contamination and pose risks to meat safety.

Additionally, carcass processing was shown to be another high-risk practice, despite moderate hygiene, as it may lead to cross-contamination during handling and evisceration. In conclusion, the table identifies key areas of slaughterhouse management that are creating significant public health risks and stress the need for better hygiene, infrastructure and enforcement.

Other identified risks included absence of isolation facilities, free animal movement, low vaccines and inadequate feeding. This finding is supported by prior research that has shown poor biosecurity and lack of veterinary services contribute to significant livestock disease burden in urban livestock production (Agribusiness Support Fund, 2013; Hussain *et al.*, 2019).

Table 2 presents the major farm-level risk factors of disease transmission in cattle in Karachi. Lack of proper waste management was observed in 32% of farms and is a significant environment risk factor, contributing to the survival and transmission of pathogens such as anthrax. Qualitative assessments also suggest that failure to isolate animals and free movement of animals are common, which greatly facilitates the spread of contagious diseases such as Foot and Mouth Disease (FMD) and Lumpy Skin Disease (LSD).

Lack of vaccination and poor hygiene were also observed as important factors contributing to the vulnerability of diseases, including mastitis and parasites. Moreover, a lack of veterinary services means that diagnosis and treatment are delayed, enabling infections to advance and spread in the herd. These insights therefore reveal inconsistent farm management and biosecurity practices, which are central to disease dynamics and the risk of disease transmission to both human and animal health.

Table 1: *Comparative risk assessment of slaughterhouse operational areas in Karachi.*

Operational area	Hygiene score	Risk level	Major Issue identified
Slaughtering floor	Low	High	Blood accumulation, poor cleaning
Equipment handling	Moderate	Moderate	Inconsistent sterilization
Waste disposal	Low	High	Improper waste management
Carcass processing	Moderate	High	Cross-contamination
Meat storage	Low	High	Lack of refrigeration
Inspection system	Moderate	Moderate	Weak enforcement

Table 2: *Major farm-level risk factors influencing disease transmission in Karachi.*

Risk factor	Observation (%)	Impact on disease spread
Poor waste disposal	32%	Environmental contamination, anthrax risk
Lack of animal isolation	High	Rapid disease transmission
Uncontrolled animal movement	High	Spread of FMD, LSD
Inadequate vaccination	Moderate–High	Increased susceptibility
Poor hygiene practices	High	Mastitis, parasitic infections
Limited veterinary access	Moderate	Delayed diagnosis and treatment

Table 3: *Assessment of slaughterhouse hygiene and compliance levels in Karachi.*

Parameter	Observation level	Compliance (%)	Remarks
Availability of clean water	Moderate	62%	Inconsistent supply during peak hours
Equipment sanitation	Low–Moderate	48%	Irregular cleaning between carcasses
Worker personal hygiene (PPE)	Low	35%	Limited use of gloves, boots, aprons
Floor and surface cleanliness	Moderate	55%	Blood and waste accumulation observed
Drainage system	Low	42%	Blockages and stagnant wastewater
Waste disposal system	Low	38%	Open dumping and delayed removal
Veterinary inspection presence	High	78%	Present but inconsistently enforced

Table 4: *Comparative analysis of farm-level and slaughterhouse conditions affecting cattle health and meat safety in Karachi.*

Parameter	Farm-level conditions	Slaughterhouse conditions	Overall impact
Hygiene	Poor sanitation, unclean sheds	Moderate, but inconsistent maintenance	High contamination risk
Biosecurity	Weak (no quarantine, uncontrolled movement)	Limited (inspection present but incomplete)	Disease persistence
Waste disposal	Improper carcass disposal	Inadequate large-scale waste management	Environmental hazards
Veterinary Role	Limited access and irregular treatment	Structured inspection system	Partial disease control
Outcome	High disease prevalence	Risk of contaminated meat	Public health concern

Slaughterhouse management and hygiene

Slaughterhouse observations showed that although formal processes such as ante-mortem and post-mortem inspections were carried out, hygiene and waste management were poor. Specific problems were inadequate disposal of biological waste, lack of fresh water, poor cleaning of equipment and potential for cross-contamination during carcass handling.

Although slaughterhouses have veterinary oversight, these factors limit the role of the abattoir as a key point of control for meat safety. Other research has documented poor hygiene conditions in abattoirs in Karachi, which were associated with increased risk of contamination (Soomro *et al.*, 2021).

Table 3 shows the degree of compliance with critical hygiene criteria in Karachi slaughterhouses. It shows that although basic requirements, such as the presence of clean water (62%) and veterinary inspections (78%) are comparatively well met, their efficacy is limited by the lack of consistent supply and enforcement. Essential hygiene attributes, such as waste management (38%), drainage (42%) and personal hygiene of workers (35%) showed poor compliance, suggesting severe operational shortcomings.

Relatively high compliance observed in floor cleanliness (55%) and equipment cleaning (48%)

indicates partial commitment to hygiene; however, the occurrence of blood and waste material, and irregular cleaning, increases the potential for microbial contamination. Taken together, the table shows that while systems are in place, deficiencies in implementation, maintenance and practices reduce the efficacy of slaughterhouse control measures, increasing the risk of meat safety and human health issues.

Comparative assessment of farm and slaughterhouse systems

Our comparative analysis showed that problems at the farm level impact slaughterhouses. Lack of hygiene, biosecurity, and high prevalence of disease at the farm level result in higher risk of diseased animals arriving at the slaughterhouses. This, along with poor slaughter practices, increases the risk of meat contamination.

These results support a notion of a continuous farm-to-slaughter risk pathway, with farm-level issues having a cascading effect. Slaughterhouse studies show that diseases like bovine tuberculosis are commonly identified in slaughterhouses, suggesting that disease control at the farm level is not adequate (Farooq *et al.*, 2023).

Table 4 compares the farm and slaughterhouse conditions affecting cattle health and meat safety

in Karachi. This table shows that the farm-level conditions are generally less established than slaughterhouses, particularly hygiene, biosecurity and waste management. Insufficient hygiene and biosecurity measures on farms lead to a high prevalence of disease, forming a major source of contamination for the slaughterhouse system.

While slaughterhouses have more formalised systems (such as veterinary checks), they are not effectively supported by proper hygiene practices and waste disposal. This disparity between upstream (farm level) and downstream (slaughter level) conditions results in a risk chain, whereby diseased animals from poorly managed farms are processed in less-than-ideal conditions, leading to an increased risk of contaminated meat reaching the market.

In conclusion, the table emphasises that both farm and slaughterhouse shortcomings together pose a risk to public health, advocating for an integrated farm-to-slaughterhouse approach, as per the One Health principle.

Table 5: District-wise comparative risk assessment index (CRAI) scores in Karachi.

District	FM	BS	SD	FS	VD	SH	CRAI value
Korangi	2	2	1	2	2	3	3.00
Malir	2	2	2	2	2	3	3.33
West	2	2	2	2	3	3	3.67
East	3	3	2	3	3	3	4.67
South	3	3	3	3	3	4	3.75
Central	4	3	3	3	3	4	4.00

Table 5 shows the spatial distribution of the Comparative Risk Assessment Index (CRAI) for various districts of Karachi in Pakistan based on the main components such as farm management (FM), biosecurity (BS), sanitation and disposal (SD), feed and water safety (FS), veterinary availability (VD) and slaughterhouse hygiene (SH). The findings show

marked differences in risk levels among districts.

The highest CRAI value (4.67) was observed in East district, reflecting a high-risk level due to moderate-to-low levels in several components including sanitation and slaughterhouse hygiene. Central district also demonstrated a high CRAI value (4.00), indicating ongoing risk despite relatively good farm management performance scores. On the other hand, Korangi (3.00) and Malir (3.33) had moderate risk scores, primarily driven by low sanitation, biosecurity, and farm management scores.

West (3.67) and South (3.75) districts showed moderate to high risk, due to a mix of farm concerns and slaughterhouse hygiene issues. In conclusion, the CRAI analysis suggests that districts with higher risk scores are associated with lower scores for farm management and sanitation, underscoring the need for a holistic approach to control measures in both the farm and slaughterhouse. This evidence supports the application of CRAI to prioritise risk areas and control measures.

The scoring system applied to develop the Comparative Risk Assessment Index (CRAI) for assessing cattle health and meat safety in Karachi is provided in Table 6. The variables encompass key elements of the livestock production system from farm management (FM) to slaughterhouse hygiene (SH). A common scoring scale of 1 to 5 was used to maintain uniformity of the assessment, where 1 is poor and 5 is ideal.

The scoring criteria for these variables were developed according to observable criteria such as housing, vaccination, waste management, feed and water quality, veterinary care and slaughterhouse hygiene. This scoring approach allowed the inclusion of multiple risk factors into a composite risk index (CRAI), facilitating district-level comparisons and offering a quantitative measure to pinpoint areas of high risk and prioritise actions.

Table 6: Scoring criteria for variables used in the comparative risk assessment index (CRAI) in Karachi.

Variable	Component description	Scoring range	Criteria (Example)
FM	Farm Management (housing, hygiene, density)	1–5	1 = Poor, 5 = Excellent
BS	Biosecurity (vaccination, isolation, movement)	1–5	1 = No control, 5 = Strict control
SD	Sanitation and Disposal (waste handling)	1–5	1 = Improper, 5 = Proper system
FS	Feed and Water Safety	1–5	1 = Contaminated, 5 = Clean/safe
VD	Veterinary Access	1–5	1 = None, 5 = Regular veterinary care
SH	Slaughterhouse Hygiene	1–5	1 = Poor, 5 = Highly hygienic

Table 7: *Evaluation of slaughtering practices and associated risks to meat safety in Karachi.*

Slaughtering step	Practice observed	Risk level	Potential impact on meat safety
Ante-mortem inspection	Conducted but not thorough	Moderate	Diseased animals may pass undetected
Slaughtering method	Traditional/manual	Moderate	Increased contamination risk
Skinning process	Performed on floor in some cases	High	Cross-contamination from hide to carcass
Evisceration	Improper handling of internal organs	High	Fecal contamination
Carcass washing	Limited use of clean water	Moderate	Incomplete removal of contaminants
Meat transportation	Open vehicles without refrigeration	High	Microbial growth and spoilage

Table 8: *Evaluation of slaughterhouse infrastructure and operational adequacy in Karachi.*

Parameter	Status observed	Adequacy level	Remarks
Slaughtering space	Overcrowded	Low	High throughput, limited space
Cold storage facilities	Limited/Absent	Low	No proper meat preservation
Water supply system	Irregular	Moderate	Affects cleaning and sanitation
Waste disposal infrastructure	Inadequate	Low	Major sanitation concern
Worker training	Limited	Low	Lack of hygiene awareness
Regulatory enforcement	Partial	Moderate	Weak implementation of standards

Corroborating evidence from veterinary and market systems

Veterinary observations revealed the prevalence of infectious and productivity diseases such as mastitis, anthrax, FMD and brucellosis. Livestock from poorly managed farms were more likely to suffer from severe disease, suggesting the impact of farm management on animal health. This is consistent with other studies that note the impact of poor management on disease progression (Hussain *et al.*, 2019).

Table 7 provides a risk assessment of major slaughtering activities and their impact on meat safety in Karachi. The results suggest that there are significant problems with various key points in the slaughtering process. Skinning and evisceration steps are of particular concern due to their high risk, as skinning on the ground and mishandling of intestines and other organs enhance the risk of contamination and faecal contamination of carcasses, respectively.

Low risks were found in ante-mortem inspection, slaughtering and carcass washing practices, largely resulting from ineffective inspection processes, traditional manual slaughtering practices and insufficient water use, respectively. Further, meat transportation (particularly open unrefrigerated vehicles) represents a high risk as it favours microbial growth and spoilage. These results underline shortcomings in slaughtering practices that impact meat safety and call for better hygiene standards,

infrastructure and regulation.

Visits to meat processing units and supermarkets suggested better hygiene and appropriate cold chain management in formal retail outlets. But the quality of meat products is dependent on upstream factors, such as animal health and slaughter practices, pointing to value chain control (World Bank, 2022).

Table 8 shows the adequacy of slaughterhouse infrastructure and operations in Karachi. The results show that key elements such as slaughtering area, cold storage, waste management and training are in the low adequacy group, suggesting substantial infrastructural and operational inadequacies. The crowded slaughtering zone and lack of adequate cold storage facilities are especially problematic and contribute to contamination and quicker spoilage of meat.

The water supply system and regulatory enforcement were rated as having average adequacy; however, insufficient water availability affects sanitation and hygiene practices, while only partial enforcement of regulations hampers compliance with hygiene standards. Inadequate worker training also compounds these problems, by decreasing knowledge and practice of safe handling. As the table illustrates, inadequate infrastructure and institutional oversight are key factors affecting the performance of slaughterhouses, which in turn affects meat safety and human health.

Table 9: Classification of CRAI (contamination risk assessment index) values.

CRAI value range	Risk level	Interpretation
< 3.0	Low risk	Good management and hygiene
3.0 – 4.0	Moderate risk	Some deficiencies present
> 4.0	High risk	Poor management and high contamination risk

The Contamination Risk Assessment Index (CRAI) as explained in Table 9, offers a systematic approach to assess the risk of contamination based on the management and hygiene conditions. Low risk (less than 3.0) means adequate management and hygiene practices are in place, thus reducing the risk of contamination. CRAI values of 3.0–4.0 are considered moderate risk, indicating that there are some management or hygiene issues that could be improved to reduce contamination risk. CRAI values greater than 4.0 represent high risk and indicate both poor management and poor hygiene conditions, presenting a high risk for contamination. In summary, the scale of the CRAI provides a useful interpretation of risk levels and helps identify areas in need of improvement.

Table 10: Component-wise contribution to overall contamination risk (%) and corresponding key issues identified in management, biosecurity, sanitation, feeding, veterinary access, and slaughter hygiene practices.

Component	Contribution to risk (%)	Key issue identified
FM	22%	Poor housing and overcrowding
BS	18%	Weak vaccination and movement control
SD	20%	Improper waste disposal
FS	15%	Contaminated feed/water
VD	10%	Limited veterinary access
SH	15%	Inadequate slaughter hygiene

Table 10 shows the distribution of the components to the risk of contamination reveals that farm management (FM) is the greatest contributor (22%) due to inadequate husbandry practices and overcrowding, which can lead to the transmission of pathogens. Sanitation and disposal (SD) also play a significant role (20%), suggesting that inadequate waste management is a significant risk factor. Biosecurity (BS) accounts for 18% of the risk, suggesting that vaccination and animal movement

are not fully managed. Feed safety (FS) and slaughter hygiene (SH) each represent 15% of the risk, reflecting potential contamination through feed or water, and poor hygiene during slaughter. Access to veterinary services and disease control (VD) is the smallest (10%), but low access to veterinary services remains an issue. The overall distribution of the scores indicates that management, hygiene and biosecurity are the risk factors for contamination and should be targeted.

Key findings

In conclusion, the findings show that mastitis, anthrax and FMD are the most common diseases among cattle in Karachi. There are substantial differences between districts in number of diseases, Korangi, Malir and West are hotspots. Lack of good farm management practices is linked to disease prevalence, and slaughterhouse hygiene is a source of contamination risk. The results confirm the interlinkage between farm and slaughterhouses, which have a combined impact on cattle health and meat safety.

Discussion

In this study, we used a Comparative Risk Assessment Index (CRAI) to assess the impact of farm management and slaughterhouse practices on cattle health and meat safety in Karachi. The CRAI approach offered an integrated approach to assessing risk along the livestock value chain, showing considerable geographical variation and identifying key control points at both upstream (farm) and downstream (slaughterhouse) ends of the value chain.

Integrated risk across the farm-to-slaughter continuum

The CRAI model shows that risks to animal health and meat safety are not limited to one step of the production chain but are cumulative. Districts like Korangi, Malir and West had moderate CRAI values, largely due to poor farm management (poor hygiene, biosecurity and uncontrolled movement of animals). Our findings demonstrate the idea that the level of risk is set at the farm level and is subsequently magnified at slaughter and processing. Such findings have been reported in livestock production systems where poor management practices result in high pathogen load and disease risk (Hussain *et al.*, 2019).

On the other hand, districts like East and Central had a higher CRAI score due to a combination of good

farm conditions and poor slaughterhouse conditions. This suggests that even if the farm conditions improve, poor slaughterhouse conditions can maintain or increase risks. The CRAI model therefore supports the idea of interdependence of the two systems and the importance of a “farm-to-slaughter” approach.

Majority of farm-level risks

The breakdown of CRAI into components showed that farm management (FM) and sanitation and disposal (SD) were the major risk factors. Inadequate housing and waste management and overcrowding were significantly linked to increased disease prevalence, including mastitis and anthrax. This is consistent with other studies which show environmental and hygiene factors are critical risk factors for the transmission of infectious diseases in livestock populations ([World Bank, 2022](#)).

Poor biosecurity practices (BS) such as low vaccination rates and failure to isolate infected animals also contributed to disease outbreaks. Endemic diseases like Foot and Mouth Disease (FMD) and Lumpy Skin Disease (LSD) in the region are indicative of poor preventive health and surveillance practices ([Sadiq et al., 2023](#)). Insufficient veterinary services (VD) also resulted in delayed treatment, leading to higher morbidity and disease spread within herds.

Slaughterhouse hygiene as a crucial control point

While the farm-level factors were the most important, the CRAI model showed that slaughterhouse hygiene (SH) is a critical control point for final meat quality. Many districts had moderate farm scores, but poor slaughterhouse hygiene which translated to high CRAI scores. The observed issues that include lack of proper disposal of the waste, equipment sanitation and cold storage favour microbial growth and spoilage.

This is like the studies on abattoir hygiene in developing urban systems, which point out that poor sanitation and enforcement of regulatory measures affect meat safety even if the animals are healthy ([Soomro et al., 2021](#)). While Karachi slaughterhouses have veterinary inspection programs, their effectiveness is constrained by limited resources and weak enforcement.

Spatial variation and high-risk zones

The CRAI-based spatial analysis identified Korangi, Malir, and West as priority intervention zones, characterized by moderate-to-high risk levels.

These districts combine high livestock density with poor farm management and limited sanitation infrastructure, creating ideal conditions for disease persistence and transmission. In contrast, Central and South districts exhibited relatively lower risk levels, suggesting that improvements in management practices and infrastructure can effectively reduce overall risk.

This spatial heterogeneity highlights the importance of targeted interventions rather than uniform policy approaches. Resource allocation should prioritize high-risk districts where the potential for disease spread, and meat contamination is greatest.

Implications for public health and food safety

The integration of farm-level and slaughterhouse variables through CRAI provides important insights into public health risks associated with meat consumption. High CRAI values indicate increased likelihood of contaminated meat entering the food chain, potentially leading to foodborne illnesses and zoonotic disease transmission. Diseases such as brucellosis and bovine tuberculosis, identified in the study, pose direct risks to human health, particularly among individuals involved in livestock handling and meat processing ([Fatima et al., 2008](#); [Farooq et al., 2023](#)).

The findings support the One Health approach, which emphasizes the interconnectedness of animal health, human health, and environmental factors. Addressing risks at only one stage of the value chain is insufficient; instead, coordinated interventions across all stages are required to ensure safe and sustainable livestock production.

One health interpretation of CRAI findings

The findings of this study strongly align with the principles of the One Health framework, which emphasizes the interconnectedness of animal, human, and environmental health. The CRAI model developed in this study demonstrates that risks to meat safety and public health are not isolated within a single domain but arise from cumulative interactions across farm management, environmental conditions, and slaughterhouse practices. Higher CRAI values observed in several districts indicate that deficiencies in animal health management and environmental sanitation can directly translate into increased risks for human populations through contaminated meat

and zoonotic disease transmission. These findings are consistent with global evidence suggesting that integrated surveillance and control strategies are essential for managing livestock-associated health risks (World Health Organization, 2017; World Organisation for Animal Health, 2021).

Zoonosis and health risks

The one health perspective acknowledges that zoonotic diseases like brucellosis and bovine tuberculosis in cattle is a key animal-human health interface. The CRAI study suggests that poor farm management and biosecurity in districts are associated with the presence of such infections, which can lead to occupational risks for farmers, slaughterhouse workers, and meat handlers. Additionally, poor slaughterhouse practices may allow infected meat to enter the food supply, thus impacting human health. Our findings are consistent with other studies showing that zoonotic diseases can survive and spread in unregulated livestock production, especially in urban environments in developing countries (Fatima *et al.*, 2008; Farooq *et al.*, 2023).

Environmental health and disease persistence

The one health environment component is shown in the CRAI section of sanitation and waste disposal (SD). Insufficient disposal of waste and carcasses, as observed in some of the sites, leads to environmental contamination and disease persistence. This may act as a source of infection for livestock and potentially humans via the water and soil. This pathway is significant in urbanised and densely populated areas like Karachi, where livestock and humans are in close contact. This has also been noted in other livestock studies globally that refer to environmental contamination in the maintenance of disease (Food and Agriculture Organization of the United Nations, 2013).

Slaughterhouses as a one health control point

Slaughterhouses are a one health control point that can help mitigate or spread the risk of disease. Our CRAI analysis suggests that while farm conditions have improved, poor hygiene in slaughterhouses can still pose a high risk. This indicates the importance of better slaughterhouse sanitation, waste management and inspection to prevent diseases and ensure quality meat production. Slaughterhouses are a well recognised animal/human health interface, particularly in urban meat processing, where large volumes of meat are

processed (Soomro *et al.*, 2021; World Bank, 2022).

Policy and practical implications

The CRAI approach can help policymakers and stakeholders to identify areas of greatest risk and target mitigation strategies. The results suggest that:

- Improving on-farm biosecurity via vaccination and education
- Better managing waste to minimise environmental pollution
- Improving veterinary services and surveillance
- Improving slaughterhouse facilities, such as hygiene and cold chain
- Implementing hygiene standards and training slaughterhouse workers

These measures should be applied in a holistic approach to improve cattle health and meat safety.

Policy implications under one health framework

The one health approach to integrating CRAI offers a framework for policymakers to implement interventions to reduce risks throughout the livestock value chain. A one health approach suggests a combination of strategies, rather than disease control or slaughterhouse management alone.

Strengths and limitations of the CRAI approach

This study builds on the creation of the CRAI, which combines several risk factors into a composite indicator, enabling comparisons between districts. This offers a more holistic view of risk than focusing solely on farm or slaughterhouse risk factors.

But the study has limitations. CRAI scoring system is somewhat subjective, and all variables were weighted equally. Future research could improve the model by considering weighted scoring and statistical analyses for greater accuracy and predictive value.

Conclusion

Overall, the CRAI-based analysis demonstrates that cattle health and meat safety in Karachi are shaped by interconnected risk factors spanning farm management and slaughterhouse practices. Farm-level deficiencies remain the primary drivers of disease burden, while slaughterhouse hygiene determines the final safety of meat products. The study highlights the need for integrated, multi-sectoral interventions to reduce risk and improve public health outcomes in

urban livestock systems.

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Novelty Statement

This study proposes a new approach to the integration of CRAI (Comprehensive Risk Assessment and Indexing) analysis with One Health to comprehensively assess cattle farm systems. This study examines the interrelated effects of animal health, human health and environmental sustainability as opposed to traditional livestock assessments which only consider animal productivity or disease prevalence. The research offers a multi-dimensional risk assessment tool based on CRAI analysis that can assist with informing evidence-based policy making, sustainable livestock production, and early detection of public health risks in integrated farming systems.

Author's Contribution

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