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Review Article

Water Contamination in Livestock Production: Impacts, Causes, and Mitigation Strategies

Marothi Vincent Sebela and Khetho Ratshilumela Nemutandani

Department of Agricultural Economics and Animal Production, University of Limpopo, South Africa

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Corresponding Author:
khetho Ratshilumela Nemutandani
Department of Agricultural Economics and Animal Production, University of Limpopo, South Africa
Email: khetho.nemutandani@ul.ac.za

Abstract: Water contamination poses a significant threat to sustainable livestock production, directly affecting animal health, productivity, and product safety. This systematic review synthesizes existing literature on the impacts, causes, and mitigation strategies of water contamination in livestock production systems. A systematic literature search was conducted across Google Scholar, PubMed, and ScienceDirect databases using key terms including "water contamination," "livestock," and "water pollution," restricted to peer-reviewed studies published between 2014 and 2024. The findings identify agricultural activities-particularly intensive livestock farming-as primary contributors to water pollution through nutrient runoff, pesticide application, and improper waste management. Key contaminants, including pathogens, agricultural chemicals, and excess nutrients, adversely affect livestock health by reducing growth rates, impairing reproductive performance, and increasing disease susceptibility. Water contamination also exacerbates broader environmental challenges, including eutrophication and biodiversity loss. Reviewed studies consistently emphasize best management practices as effective mitigation strategies, including improved waste management systems, reduced chemical inputs, and comprehensive watershed protection measures. However, effective adoption of these strategies is frequently impeded by limited water resources, inadequate infrastructure, and fragmented policy frameworks. Addressing water contamination in livestock production requires concerted and coordinated efforts in evidence-based policy development, stakeholder capacity building, and public engagement to ensure both sustainable livestock practices and long-term water resource conservation.

Keywords: Water Contamination, Livestock Production, Water Quality, Agricultural Pollution, Animal Health, Nutrient Runoff, Best Management Practices, Sustainable Agriculture

Introduction

Water is an indispensable nutrient in livestock production, vital for maintaining animal hydration and enabling essential physiological functions (Akinmoladun et al., 2019; Heinke et al., 2020). Despite its critical role, contaminated water presents a considerable and growing threat to the livestock sector. Water contamination is defined as the presence of harmful substances or pollutants in water sources, making them unsuitable for their intended use (Singh et al., 2020). These contaminants can compromise animal health, reduce productivity, and, in severe cases, lead to livestock fatalities (Alegbeleye and Sant'Ana, 2020). The array of water pollutants includes chemicals, heavy metals, pathogens (such as bacteria, viruses, and parasites), pesticides, pharmaceuticals, and other emerging contaminants, all of which pose risks to human, animal, and environmental health (Rathi et al., 2021). As noted by Chagas et al. (2014), contaminated water can introduce harmful substances and pathogens into animals, resulting in diseases, decreased feed intake, stunted growth, and reproductive problems. The intensification of modern farming practices has increasingly raised environmental concerns due to elevated pollution loads (Wang et al., 2021).

The expansion of livestock farming significantly contributes to water pollution. The concentration of large animal populations in confined spaces generates substantial amounts of waste, including manure and urine. While livestock waste contains valuable nutrients, it is often viewed as a disposal challenge rather than a beneficial resource (Maurya et al., 2020). This often results in manure being applied to agricultural fields at suboptimal times, further compromising water quality. Beyond direct waste, livestock farming contributes to water pollution through nutrient runoff and the improper disposal of silage and manure slurry (Cesoniene et al., 2019). Even less considered factors, such as chemicals from sheep dip and pathogens from animals, can degrade water quality. Therefore, regular evaluation of water quality for livestock consumption is paramount. Such assessments are crucial for safeguarding both animal and consumer health, while simultaneously fostering sustainable and responsible management practices in livestock agriculture (Ighalo and Adeniyi, 2020).

While existing research addresses various aspects of livestock water contamination, there remains a need for a holistic perspective that integrates the complex interactions of contaminants, their diverse sources within farming systems, and their cascading impacts on livestock and the environment. This systematic review, encompassing literature from 2014 to 2024, aims to bridge these gaps by synthesizing research on major contamination sources and types, their effects on livestock, and current mitigation strategies. By consolidating this knowledge, the review seeks to identify critical areas for future research to develop sustainable solutions for water protection and ensure the long-term health and productivity of livestock.

Materials and Methods

Eligibility Criteria

The Population, Exposure, and Outcomes (PEO) components of the research question were defined as follows: the Population was "livestock", the Exposure was "water contamination", and the Outcome was "livestock production" (including parameters such as milk yield, production performance, and consumption of feed and water) and "environmental health" (specifically addressing soil contamination, water eutrophication, and greenhouse gas emissions directly linked to water contamination in livestock systems). To ensure the review captured relevant and up-to-date information reflecting recent advancements and current challenges, only peer-reviewed research articles published in English within the last ten years (2014 to 2024) were considered.

Literature Search

A comprehensive search strategy was employed to identify relevant studies across several electronic databases known for their extensive coverage of scientific literature, including peer-reviewed journals, diverse research topics, and biomedical sciences: ScienceDirect, Google Scholar, and PubMed. The search strategy utilized a combination of the following keywords and Boolean operators to ensure a thorough capture of pertinent literature: ("water contamination" OR "water pollution" OR "feedlot runoff" OR "manure management") AND ("livestock" OR "cattle" OR "poultry" OR "pigs" OR "sheep") AND ("production" OR "health" OR "growth" OR "yield" OR "reproduction" OR "mortality" OR "environment" OR "soil contamination" OR "eutrophication" OR "greenhouse gas"). The search was limited to articles published in English.

Inclusion Criteria

The titles and abstracts of all articles retrieved through the search were independently screened by two reviewers (Marothi Vincent Sebela and Khetho Ratshilumela Nemutandani) against the predefined eligibility criteria. Duplicate articles were removed before screening. Studies were included if they met all the outlined criteria:

(1) they were peer-reviewed research articles
(2) they clearly described a livestock population exposed to water contamination and reported outcomes related to either livestock production or the specified environmental health aspects
(3) they were published between the years 2014 and 2024
(4) the full article was available in English. Full-text articles of potentially eligible studies were subsequently retrieved for a more detailed assessment

Exclusion Criteria

During the initial screening phase, duplicate studies were identified and removed by comparing titles and abstracts using keywords. In the full-text screening phase, studies were excluded if they met any of the following criteria: they were published outside the 2014-2024 timeframe, they did not address water contamination as a primary exposure or its direct impacts on livestock or the specified environmental health outcomes, or they were not available in English.

Quality Assessment Criteria

The methodological quality of the studies incorporated into this systematic review was assessed to evaluate their internal validity and mitigate potential biases. This appraisal was independently conducted by two reviewers, utilizing relevant critical appraisal tools from the Joanna Briggs Institute (JBI) System for the Unified Management, Assessment and Review of Information (SUMARI). Given the diverse nature of the primary research, including both observational and quasi-experimental designs, the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies and the JBI Critical Appraisal Checklist for Quasi-Experimental

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Studies were predominantly applied. Low risk indicates clear methodologies; moderate risk signals some limitations or unclear descriptions; and high-risk flags significant concerns about bias. We focused on three key areas of bias risk:

i. Sample representativeness, to assess how well a study's participants or sources reflect the broader target population, influencing how generalizable its findings
ii. Confounding control, primarily for observational studies to evaluate if the study adequately identified and managed variables that could distort the true relationship between water contamination and outcomes
iii. Outcome or exposure measurement to examine the validity and reliability of how both the contamination (exposure) and its impacts (outcomes) were measured

Data Extraction

Two reviewers (Marothi Vincent Sebela and Khetho Ratshilumela Nemutandani) independently extracted data from the included full-text articles using a standardized data extraction form. Any disagreements encountered during the data extraction process were resolved through thorough discussion and consensus between the two reviewers. In instances where consensus could not be reached, a third reviewer would have been consulted to make the final decision. The following data items were extracted: name of the first author, year of publication, country where the study was conducted, type of water contaminant identified, source of water contamination, specific effects on livestock health, specific effects on livestock production, and specific effects on environmental health.

Results

A comprehensive literature search was conducted using relevant databases (ScienceDirect, Google Scholar, and PubMed) to identify studies on water contamination in livestock production. As depicted in the PRISMA flow diagram (Fig. 1), the search strategies initially identified a total of 124 articles. Following the removal of 9 duplicate records and an initial screening of titles and abstracts for relevance based on the inclusion criteria, 73 articles were deemed eligible for full-text screening. Subsequent full-text screening resulted in the exclusion of 42 articles, with the primary reasons being publication before 2014 (n = 29) and lack of full article or not available in English (n = 13). In the end, 31 articles satisfied the inclusion criteria and were incorporated into this systematic review.

Characteristics of Included Articles

Thirty-one (n = 31) articles, out of the initial 124 identified, were retained for inclusion in this systematic review (Table 1). These studies were published within the specified period of 2014 to 2024. The methodologies employed in the included studies were clearly described, encompassing approaches such as observational studies with defined exposure and outcome measures, and experimental studies assessing the impact of contaminated water on livestock. The methodological quality of the 31 included studies was assessed using relevant JBI Critical Appraisal Checklists based on their presumed study designs. Risk of bias is summarized as low, moderate, or high for key domains. While many of the included studies are review articles, those that involved primary data collection such as analytical cross-sectional and quasi-experimental studies frequently exhibit moderate risk of bias, particularly concerning sample representativeness and control for confounding factors. The scope of these studies was broad, covering various aspects of water contamination in livestock production. A significant proportion of the research investigated the sources and impacts of water contamination, with a particular emphasis on the role of manure and agricultural runoff. Other studies focused on the occurrence of specific contaminants, including pathogens, various chemicals, and salts, in water sources utilized by diverse livestock species (cattle, poultry, pigs, and sheep).

Origin of the Publications

The included studies originated from diverse geographical regions across Africa, Asia, Europe, North America, and South America, highlighting the global relevance of water contamination in livestock production. The geographical distribution of the included articles is visually represented in Figure 2 (bar chart illustrating the number of articles per region). Notably, approximately 7 of the included papers involved international collaborations, often between researchers from multiple continents. International collaborations in research, such as those observed in studies on water contamination in livestock production, are driven by the complex nature of global challenges and the desire to maximize scientific impact. For instance, Wardrop et al. (2021) utilized survey data from households across Nepal, Bangladesh, and Ghana to allow researchers to pool resources, expertise, and data from diverse regions to tackle these issues more comprehensively and develop solutions with global applicability. Following international collaborations, most included articles originated from Netherlands (4), followed by South Africa (3). Publications from other

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countries such as India, Netherlands, Pakistan, Italy, and China also constituted a noteworthy presence.

Publication by Year

The included articles were published within the past decade (2014-2024), indicating a sustained interest in this research area. While the inclusion criteria focused on this period, the distribution shows a higher number of publications in the years between 2014 and 2019 (16 relevant studies published), with a peak in 2020 (nine articles) and 2021 (eight articles), respectively. The distribution of articles by year of publication is detailed in Fig. 3.

Publication by Journals

The 31 included articles were published across a wide range of journals (Table 2). The International Journal of Hygiene and Environmental Health were the most frequently represented, with three (3) articles, followed by Animals, Chemosphere and Water Research, each with two (2) articles. The remaining 22 articles were published across 18 different journals, indicating a diverse range of publication outlets for this research.

Literature searched results

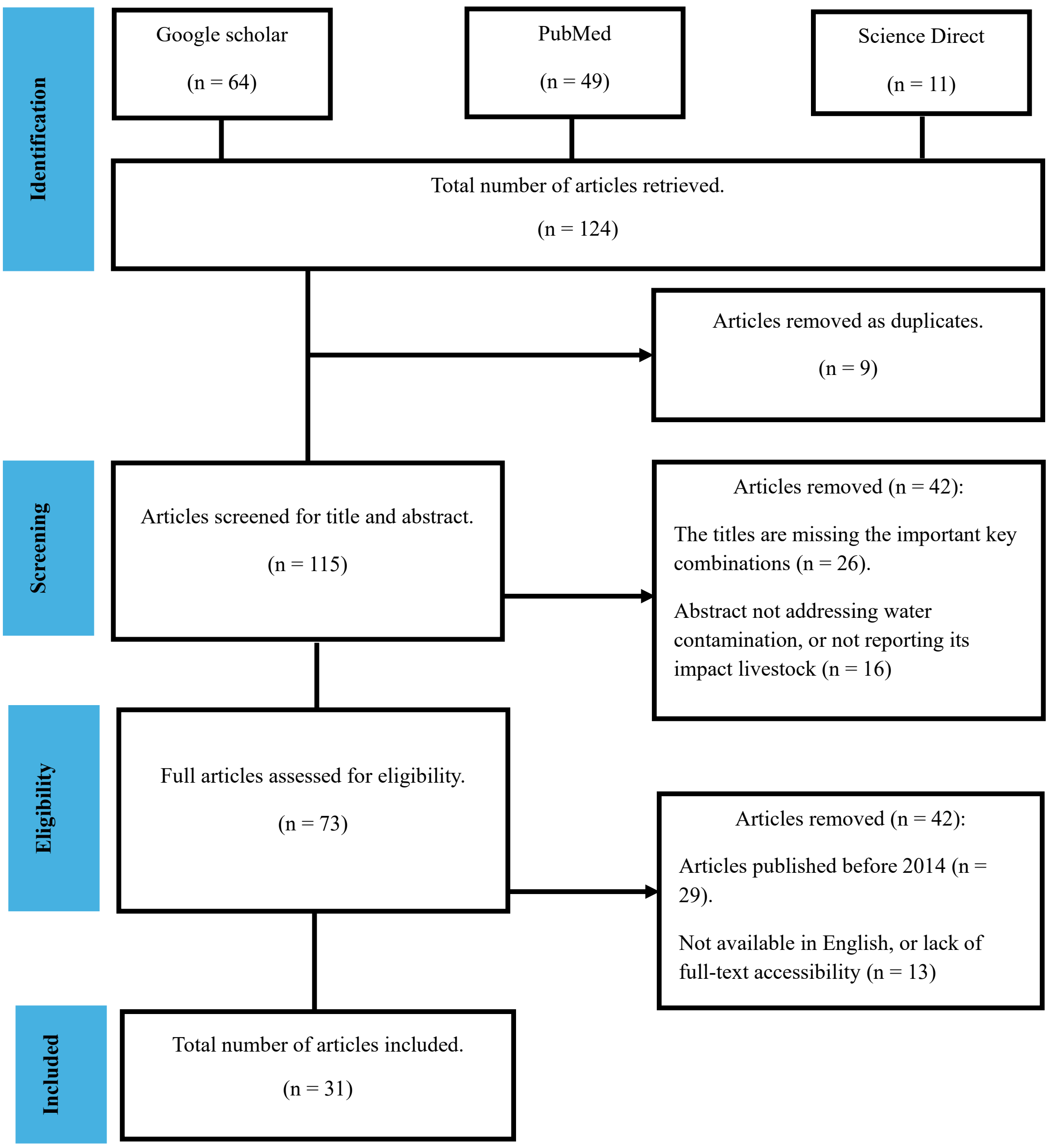

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Fig. 1: PRISMA flow diagram of the study selection process

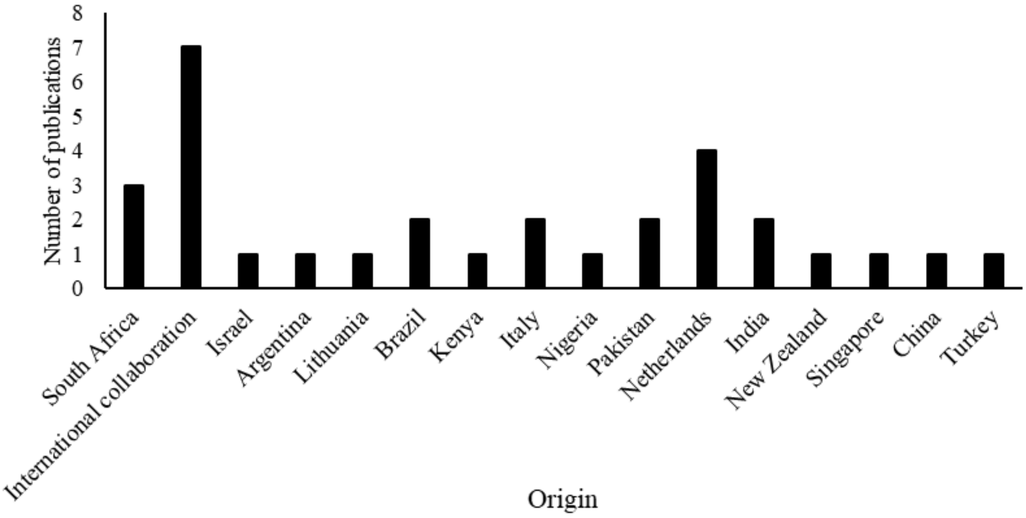

Fig. 2: Origin of publication

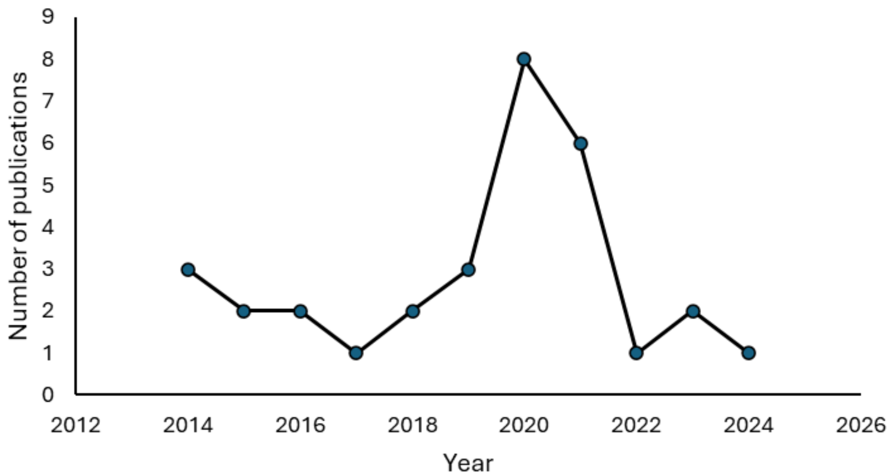

Fig. 3: Publication by year

Table 1: Characteristics of included article

Author(s)	Year	Country	Livestock species	Water contaminants type	Overall Risk of Bias Judgment
Akinmoladun *et al*.	2019	South Africa	Sheep, goats	Other influencing factors	Moderate
Alegbeleye and Sant'Ana	2020	Brazil	Not specified	Pollution sources	Low
Ben Meir *et al*.	2023	Israel	Dairy cattle	Pollution sources	Low
Chagas *et al*.	2014	Argentina	Cattle	Pathogens	Moderate
Cesoniene *et al.*	2019	Lithuania	Cattle, sheep, pigs, poultry	Pollution sources	Low
Costa *et al*.	2021	Brazil	Dairy goats	Chemical contaminants	Low
da Silva *et al*.	2020	Kenya	Cattle, goats, poultry	Pollution sources	Low
De Liguoro *et al*.	2014	Italy	Cattle	Chemical contaminants	Low
Du Preez and van Huyssteen	2020	South Africa	Not specified	Pathogens	Moderate
Edokpayi *et al*.	2018	South Africa	Not specified	Chemical contaminants	Moderate
Giammarino and Quatto	2015	Italy	Cattle, sheep, pigs, poultry	Other influencing factors	Moderate
Heinke *et al*.	2020	International collaboration	Pigs and broilers	Chemical contaminants	Low

Ighalo and Adeniyi	2020	Nigeria	Not specified	Chemical contaminants	Low
Kazi *et al*.	2016	Pakistan	Cattle, buffalos, sheep, goats, camels	Chemical contaminants	Moderate
Krol	2023	Netherlands	Beef cattle, dairy cattle, pigs, broiler chickens, laying hens	Chemical contaminants	Low
Kumar *et al*.	2021	India	Not specified	Pollution sources	Low
Li *et al*.	2022	International collaboration	Sheep, buffalo, camels, mules, cattle, chickens, ducks, donkeys, goats, horses, swine	Pollution sources	Moderate
Maurya *et al*.	2020	International collaboration	Not specified	Other influencing factors	Low
Naqvi *et al*.	2015	India	Camels, cattle, chickens, goats, swine, sheep	Chemical contaminants	Low
Pérez-Beltrán *et al*.	2024	Netherlands	Not specified	Pollution sources	Low
Rathi *et al.*	2021	Netherlands	Not specified	Pollution sources	Low
Sahoo *et al*.	2016	International collaboration	Not specified	Pollution sources	Low
Sakadevan and Nguyen	2017	International collaboration	Not specified	Pollution sources	Low
Schütz *et al*.	2021	New Zealand	Dairy cattle	Chemical contaminants	Low
Singh *et al*.	2020	Singapore	Not specified	Chemical contaminants	Low
Skandalis *et al*.	2021	International collaboration	Not specified	Chemical contaminants	Low
Umar *et al*.	2014	Pakistan	Not specified	Chemical contaminants	Low
Vermeulen *et al*.	2019	Netherlands	Cattle, buffalo, swine, sheep, goats, horses, camels, donkeys, chickens, ducks	Pathogens	Low
Wang *et al*.	2018	China	Not specified	Pollution sources	Moderate
Wardrop *et al*.	2021	International collaboration	cattle, yak, buffalo, sheep, goats, pigs, poultry	Pollution sources	Low
Yıldırır	2020	Turkey	cattle, water buffalo, sheep, goat, poultry	Pollution sources	Low

Table 2: Publication by journal

Journals	Number of articles
International Journal of Hygiene and Environmental Health	3
Chemosphere	2
Animals	2
Water Research	2
Journal of Environmental Management	1
Environmental Science and Pollution Research International	1
Spanish Journal of Agricultural Research	1
Environmental Science and Pollution Research	1
Veterinarian	1
Applied Animal Behaviour Science	1
Current Pollution Reports	1
Science of the Total Environment	1
Climate change impact on livestock	1
International Journal of Modern Agriculture	1
Integrated Environmental Assessment and Management	1
Animal Nutrition	1
Water Resources Research	1
Journal of preventive medicine and hygiene	1
Water	1
Environmental Research	1
Role of material	1
Advances in Agronomy	1
Environmental Degradation	1
Trends in Analytical Chemistry	1

Antibiotics	1

Factors Influencing Water Contamination

Table 3 presents a detailed overview of the water contaminants identified within the included articles. The predominant focus of the literature (13/31) was on pollution sources, encompassing investigations into agriculture runoffs, livestock farms, and non-point source contaminants. The analysis of water contaminants revealed that livestock farms were the most prevalent water contaminant source reported, appearing in 32% of the reviewed literature. Chemical contaminants, including dissolved solids, pharmaceutical contaminants, harmful substances, and minerals, also constituted a substantial portion (11/31). Among other contaminant types, pathogens (microorganisms) were addressed in 7%. Notably, 10% of the reviewed publications examined other influencing factors, specifically climate change.

Table 3: Distribution of analyzed articles by contaminant type and source

Type	Contaminants	Number of articles	Percentages
Contaminant sources	Agricultural runoff	4	13%
	Livestock farms	10	32%
	Non-point source contaminants	1	3%
Chemical contaminants	Dissolved solids	5	16%
	Pharmaceutical contaminants	2	6%
	Harmful chemical substances	3	10%
	Minerals	1	3%
Pathogens	Microorganisms	2	7%
Other influencing factors	Climate change	3	10%

Discussion

Sources of Water Contamination in Livestock Production

The quality of drinking water is critically threatened by contamination (Chagas et al., 2014). As global livestock output escalates to meet the demands of population expansion and dietary shifts (Li et al., 2022), intensified farming practices have been reported to pollute water bodies with various substances, including nitrogen, phosphorus, and pathogens (Umar et al., 2014). This systematic review confirms that water contamination originating from livestock activities is a global concern, impacting diverse water bodies and posing significant risks to farm animals.

The largest category of water contaminants discussed, pollution sources, predominantly encompasses livestock waste, agricultural runoff, and non-point source contaminants, highlighting the diffuse and pervasive nature of this issue. Publications consistently identify general pollution sources linked to intensive agricultural practices. For instance, studies across diverse geographies by da Silva et al. (2020) in Kenya and Cesoniene et al. (2019) in Lithuania broadly investigate pollution from various livestock operations. The direct and indirect pathways of contamination from livestock waste are well documented, including direct discharge, runoff, leaching, overflow, grazing near water bodies, and atmospheric deposition (Cesoniene et al., 2019; Yıldırır, 2020; Wardrop et al., 2021). These pathways introduce a detrimental array of substances: harmful nutrients (nitrogen and phosphorus), pathogens, organic matter, solids, heavy metals, antibiotics, and hormones. The global impact of livestock waste is widely documented, with studies highlighting its effects in specific regions like Turkey (Yıldırır, 2020) and Brazil (Alegbeleye and Sant'Ana, 2020), as well as through broader international research covering various species (Li et al., 2022). A specific example of direct contamination within the farm environment is the shedding of animal manure and urine from hooves into drinking water sources, which can alter taste and odour, consequently affecting water intake by animals (Schütz et al., 2021).

Diffuse agricultural runoff, a significant component of pollution sources, is further explained by studies examining the overall impact of farming on water quality. Li et al. (2022) provided a continental perspective on the distribution of nitrogen, phosphorus, and oocyst inputs, directly correlating them with livestock populations and species dominance (Figure 4). Asia emerges as the primary contributor of these substances due to its vast livestock numbers. While cattle are consistent global sources of nitrogen and phosphorus, and oocysts in specific regions, pigs significantly contribute to nitrogen

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and phosphorus inputs in Asia and Europe, and oocysts in Europe and North America. Chicken production also plays a crucial role in phosphorus and oocyst contributions, particularly in Asia, North America, and South America, underscoring the regional variability of environmental impacts across different animal agriculture systems. Beyond animal waste, Chagas et al. (2014) reported that improper application of fertilizers and pesticides contributes to toxins leaching into surface or groundwater via runoff. Overgrazing further compounds this by reducing soil's water absorption capacity, increasing erosion risk (Chagas et al., 2014). Wang et al. (2021) specifically identified sediments, fertilizers, and pesticides as key non-point source contaminants.

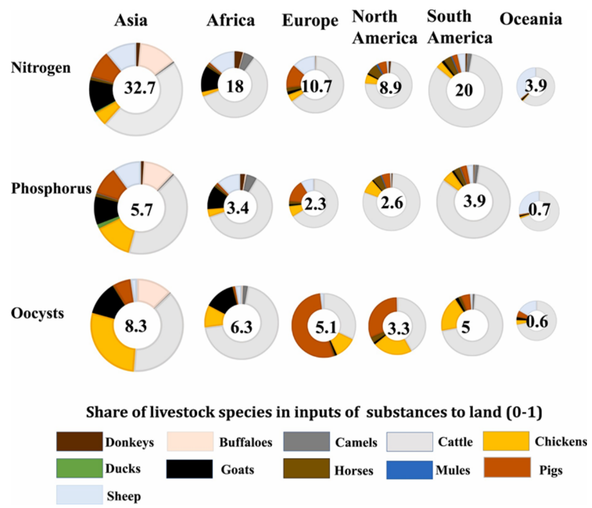

Fig. 4: Inputs Nitrogen (N), Phosphorus (P), and oocysts to land

Toxic chemicals represent another critical category of water contaminants, encompassing dissolved solids, hazardous contaminants, pharmaceutical compounds, and minerals. Kazi et al. (2016) in Pakistan highlighted arsenic concentration in livestock drinking water as a significant source of exposure affecting milk production. The increasing recognition of antibiotics as pollutants, exemplified by research from Heinke et al. (2020) (international collaboration focusing on pigs and broilers), Singh et al. (2020) in Singapore, and Skandalis et al. (2021) international collaboration in United States of America and Greece, underscores the concern about the proliferation of antimicrobial resistance through aquatic systems. These contaminants can originate from natural geological sources but are often exacerbated by agricultural practices or specific compounds present in animal waste or feed.

Mine water is an escalating concern in water quality management, as noted by Li et al. (2022), negatively impacting aquatic environments by raising suspended solids and mobilizing elements like iron, aluminium, cadmium, cobalt, manganese, and zinc, while simultaneously lowering the pH of receiving waters. The accumulation of excess nutrients from various sources promotes the growth of algae and phytoplankton, creating breeding grounds for bacteria and fungi (Du Preez and van Huyssteen, 2020). Beyond nutrient enrichment and water quality alteration, these contaminants pose a substantial risk of disease transmission to farm animals (Sakadevan and Nguyen, 2017; Li et al., 2022). Dissolved solids, arising from natural weathering and human activities including agriculture, industry, sewage discharge, mining, road salting, and landfills, further complicate water quality. De Liguoro et al. (2014) pointed out the growing attention on chemical contaminants, particularly veterinary drugs, hormones, and other synthetic compounds used in livestock farming, which can persist in the environment. Krol et al., (2023) in the Netherlands demonstrated that drugs used to treat infections, specifically *flubendazole* in broiler production, had the highest per-unit substance effect on water quality. Umar et al. (2014) in Pakistan emphasized that mineral levels exceeding acceptable limits can lead to toxicity, electrolyte imbalances, acid/base imbalances, and disruptions of other physiological parameters in livestock. Costa et al. (2021) in Brazil specifically linked increasing water salinity to dairy goat milk quality. While dissolved solids and minerals can cause salinization or elevated element levels, the presence of *E. coli* in all natural water sources in South Africa suggests that consuming untreated water poses a significant health risk (Edokpayi et al., 2018).

Pathogens constitute a critical category of water contaminants, directly resulting from faecal matter entering water sources and posing substantial health risks. Chagas et al. (2014) also investigated pathogens in cattle production, illustrating the direct link, and it was shown that the threat of waterborne diseases is particularly evident in areas with high livestock densities or inadequate waste management. Du Preez and van Huyssteen (2020) in South Africa identified a connection between backyard poultry farming and elevated contamination levels of *Enterococci* and *E. coli* in drinking water, underscoring an increased risk. While human waste can be a significant source, Vermeulen et al. (2019) in the Netherlands examined *Cryptosporidium* across various livestock species, emphasizing its widespread nature as a biological contaminant, though they noted human waste as a more significant source in their context.

While not a direct pollutant, climate change significantly influences and exacerbates existing contamination problems. Akinmoladun et al. (2019) reported that altered rainfall patterns, increased runoff, reduced water availability, and impacts on contaminant transport and persistence are all consequences of climate change that worsens water quality issues. Studies indicate that agricultural runoff, defined as excess water from irrigation or rainfall (Vermeulen et al., 2019), carries a complex array of contaminants, including heavy metals, phosphorus compounds, ammonium, nitrates, and persistent organic contaminants (Chagas et al., 2014). Research by Akinmoladun et al. (2019) in South Africa and Giammarino and Quatto (2015) in Italy have considered these broader environmental factors. Maurya et al. (2020), through international collaboration, further explored climate change, highlighting the growing recognition of the complex interplay between climate and water quality in livestock systems. Naqvi et al. (2015) additionally reported that increased extreme precipitation and flooding due to climate change would intensify soil erosion and the release of pollutants and toxins into streams, directly impacting water quality.

Impact of Water Contamination on Livestock and Environment

Water, recognized as the most vital nutrient, is consumed in greater quantities than any other (Edokpayi et al., 2018; Wang et al., 2021). Its suitability for livestock depends on various attributes, including colour, flavour, bacterial levels, mineral composition, salinity, and the presence of organic or inorganic substances that affect taste and consumption (Yıldırır, 2020). Contaminated water significantly impacts both livestock health and the broader environment. Unpleasant water can reduce consumption, leading to dehydration and decreased animal performance. Schütz et al. (2021) demonstrated that dairy cows consumed more clean water compared to manure-contaminated water (Figure 5), though feed intake and milk production were not affected in their specific study. Conversely, Naqvi et al. (2015) reported that high total dissolved solids (e.g., salt) can reduce feed consumption and daily weight gains in beef cattle. A decrease in water consumption due to contamination can also disrupt the body's mineral balance. While Costa et al. (2021) observed no significant change in milk production or its characteristics in dairy goats exposed to varying levels of total dissolved solids, Kazi et al. (2016) found arsenic contamination in sheep and goat milk, potentially leading to arsenic toxicity in consumers, evidenced by symptoms in parents but not children.

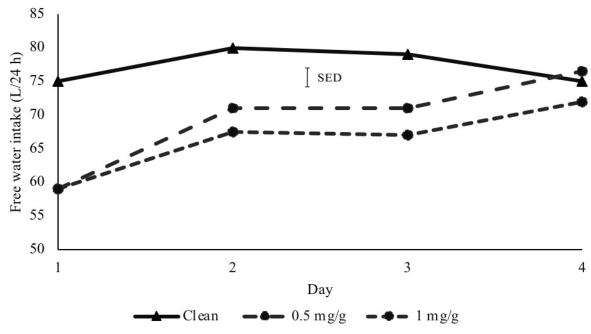

Fig. 5: Impact of manure-contaminated drinking water on 15 pregnant and lactating dairy cows' water consumption (Source: Schütz et al. 2021*)*

Contaminated water sources, both surface and groundwater, pose significant health risks to livestock (Giammarino and Quatto, 2015). While water quality may not directly cause health issues, it critically contributes to underlying problems (Yıldırır, 2020). Pathogens are a major concern in freshwater systems, causing severe gastrointestinal problems in animals (Singh et al., 2020). These pathogens, often carried by sediments, can pollute water supplies and increase the likelihood of disease outbreaks (Wang et al., 2021). International research by Wardrop et al. (2018) in Ghana, Nepal, and Bangladesh established a clear link between livestock ownership and drinking water contamination, with higher numbers of large livestock correlating with increased faecal contamination. Stagnant, low-oxygen water bodies foster disease-carrying insects and parasites, further escalating infection risk, leading to increased veterinary costs and potential animal loss (Wardrop et al., 2018). Examples include *Cryptosporidium*, causing diarrhoea and mortality in livestock (Vermeulen et al., 2019), and *Leptospira* bacteria, leading to leptospirosis, reproductive issues, and reduced milk production in cattle (Umar et al, 2014). The presence of *Salmonella spp.* in feedlot runoff highlights the persistent risk of pathogen transmission in intensive farming (Chagas et al., 2014).

Water is essential for nearly all crucial biological processes in livestock, including temperature regulation, digestion, joint lubrication, and muscle development (Umar et al, 2014). Contaminated water can lead to severe physiological disruptions. Weight loss ranging from 0.84% to 26% was observed in Awassi ewes deprived of clean drinking water (Naqvi et al., 2015). While tolerance varies, sheep, cattle, pigs, and poultry exhibit the lowest tolerance levels for water pollutants (Naqvi et al., 2015). The ability of livestock to absorb essential nutrients directly influences their production and survival (Schütz et al., 2021). Nitrites (NO2), though less common than nitrates (NO3), are highly toxic, interfering with red blood cells' oxygen-carrying capacity, potentially leading to

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suffocation and death (Umar et al, 2014). Yıldırır (2020) indicated that water quality significantly affects physiological processes like growth rate, milk yield, and reproduction. While cattle and sheep can tolerate water with up to 7,000 mg/L of soluble salts under low stress, it poses health risks for pregnant, lactating, or stressed animals (Naqvi et al., 2015). High levels of dissolved solids can also lead to mortality and health issues like dental decay and scours, impairing growth and feed efficiency (Costa et al., 2021). Excessive salts and other elements can hinder growth and reproduction, potentially causing sickness or death (Naqvi et al., 2015). Table 4 (Naqvi et al., 2015) provides a comprehensive guide for the safe utilization of saline water in livestock and poultry production, detailing acceptable total soluble salt content and associated risks. Source: Naqvi et al. (2015).

Table 4: A guide to the use of saline waters for livestock and poultry

Total soluble salt content of waters (mg/l or ppm)	Comment
Less than 1,000	Livestock and poultry can safely drink these waters because their salt content is quite low.
1,000–2,999	These waters are suitable for all types of livestock and poultry. While animals not used to these waters might experience mild, temporary diarrhoea, or poultry might have watery droppings, their overall health and performance should not be negatively impacted.
3,000–4,999	This water is generally suitable for livestock, though animals might experience temporary diarrhoea or initially reject it if they are not used to it. It is not good for poultry, as it can lead to watery droppings, higher death rates, and slower growth.
5,000–6,999	These waters are generally safe for dairy and beef cattle, sheep, swine, and horses, though it is advisable to avoid using water with higher mineral levels for pregnant animals. They are unsuitable for poultry and will likely cause issues like reduced growth, lower production, or increased deaths, especially at higher concentrations.
7,000–10,000	These waters are unsafe for poultry and likely pigs. There is also significant risk in giving them to pregnant or lactating cows, horses, sheep, their young, or any animals experiencing severe heat or dehydration. Generally, these waters should not be used. However, older ruminants and horses, or even poultry and pigs, might be able to drink them for extended periods if they're not under stress.
More than 10,000	Extremely salty water poses too high a risk to ever be recommended for use.

Heavy rainfall washes significant quantities of chemical fertilizers, pesticides, livestock manure, and soil into surface and groundwater through runoff and infiltration, leading to eutrophication (Wang et al., 2020). Umar (2014) described eutrophication as the accumulation of excessive nutrients, especially nitrogen and phosphorus, making water unpalatable. This nutrient overload triggers excessive algal growth, which can obstruct water intake points and decrease the amount of clean water available for livestock. The detrimental impacts of eutrophication are well-documented, including damage to fish spawning gravel, reduced biological productivity and light penetration, diminished recreational value, increased water treatment costs, and erosion of pumping equipment (Wang et al., 2020; Kumar et al., 2021; Rathi et al., 2021). Implementing pollution-reduction measures can effectively protect aquatic habitats, animals, and water resources (Giammarino and Quatto, 2015). However, removing sediment and related contaminants may necessitate investment in water treatment equipment, increasing water provision costs. Understanding contaminant types and their specific harm is crucial. Furthermore, overland movement coupled with degrading sediments is a major pathway for phosphorus transfer from land to water (Du Preez and van Huyssteen, 2020).

Economic Impacts and Policy Interventions

The rapid evolution of global livestock production, driven by population growth, urbanization, and rising incomes, presents significant sustainability challenges, including safeguarding land and water resources, managing manure, and reducing greenhouse gas emissions (Sakadevan and Nguyen, 2017). Environmental degradation carries substantial economic costs for nations, impacting restoration efforts, waste clean-up, and endangered species conservation (Maurya et al., 2020), and can also lead to a decline in the tourism sector. In India, where agribusiness contributes significantly to GDP, inadequate water quality and potential shortages lead to substantial economic losses (Kumar et al., 2021).

Countries often face a trade-off between investing in pollution control and other developmental priorities. In dry and water-scarce regions, anticipated rainfall declines, and population growth exacerbates the problem, threatening economies heavily dependent on natural resources and climate-based activities (Akinmoladun et al., 2019). Animal husbandry practices have profoundly impacted the environment, influencing policies and regulations globally (Alegbeleye and Sant'Ana, 2020). A key challenge is that farm managers often prioritize profit

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optimization over environmental protection, necessitating effective enforcement. Farmers' reluctance to adopt cleaner agricultural practices due to technology availability and associated expenses is a documented barrier (Yıldırır, 2020). However, increasing awareness of environmental damage from traditional methods is emerging. Governments can incentivize cleaner practices through financial support and technology training (Wang et al., 2021). Sustainable global economic development hinges on efficient water resource management, a concept supported by the World Bank's 1993 policy (Kumar et al., 2021).

Achieving water security for the entire population faces considerable challenges, including fragmented policies, conflicting duties, capacity limitations, inadequate funding, deteriorating infrastructure, bureaucratic hurdles, corruption, and insufficient public involvement (Kumar et al., 2021). Innovative governmental approaches are crucial, such as financial support for skill-enhancing training, reliable monitoring and assessment frameworks, data-informed decision-making, community involvement, and public-private collaborations (Akinmoladun et al., 2019; Kumar et al., 2021).

Challenges and Future Directions

The depletion of freshwater resources is a primary driver of environmental degradation, with global water demand continuing to rise due to climate change, population expansion, water contamination, land use alterations, and economic growth (Maurya et al., 2020; Naqvi et al., 2015; Akinmoladun et al., 2019). Contaminated water renders habitats unsuitable for many species (Cesoniene et al., 2019). The emergence of new harmful substances in agriculture, including antibiotics, antibodies, growth hormones, and pesticides (Kumar et al., 2021), can lead to population decline through direct toxicity or disruption of reproductive cycles, causing ecological succession impacts (Naqvi et al., 2015).

Future directions emphasize the development of advanced technologies. Rathi et al. (2021) highlighted accelerator mass spectrometry for immediate chemical analysis of water quality. Pérez-Beltrán et al. (2024) demonstrated the potential of spectroscopic methods combined with artificial intelligence for water quality management, offering reduced operational costs, promotion of sustainable water treatment through resource recycling, and enhancement of water and environmental quality.

Waste management remains a critically important challenge. Studies on pathogen transfer from livestock waste fields into water bodies underscore this (Chagas et al., 2014; Sahoo et al., 2016; Schütz et al., 2021). Insights into overland flow interactions with surface waters are vital, particularly concerning disease-causing emissions from different livestock, pathogen survival rates in manure, and leaching rates under varying soil types and rainfall (Alegbeleye and Sant'Ana, 2020). Therefore, a thorough exploration of pathogen survival characteristics across different manure management practices and analysis of manure properties influencing contamination potential are crucial. A more comprehensive understanding of factors influencing pathogen survival in the soil-waste environment is essential for effective mitigation.

Strategies for Reducing Water Contamination

Effective strategies for reducing water contamination in livestock production involve a multi-pronged approach encompassing regulation, clean-up, watershed management, and on-farm practices. De Liguoro et al. (2014) identified regulation, clean-up, and watershed management as key approaches to improve water quality standards. Water regulation can prevent uncontrolled discharge of waste from industry or sewage treatment plants by setting pollutant limits. For farms, proper management of solid manure piles, ensuring they rest on compacted and sealed surfaces, is crucial to prevent environmental contamination (Alegbeleye and Sant'Ana, 2020). While short-term stacking can reduce bacteria in chicken litter, its effectiveness varies with heap surface conditions and ambient temperatures.

Other farm management techniques protect the soil from raindrop force, such as maintaining plant cover or residue on the surface, which decreases microbial release and transport into nearby water, representing a financially sound solution for farmers (Alegbeleye and Sant'Ana, 2020). To manage nitrate levels, particularly in Nitrate Vulnerable Zones, Giammarino and Quatto (2015) suggested including areas with significant aquaculture. Fisheries using open farming methods in these zones must be equipped with filters and systems to remove excess nutrients and waste before releasing water. Integrating these steps into good agricultural practices could significantly lower nitrate concentrations.

Wang et al. (2021) proposed four specific actions for pollution reduction:

(1) sensible agricultural output, including formula-based fertilization via soil analysis, integrated pest management, and water-efficient irrigation
(2) safe handling of animal waste, such as aerobic composting for dry manure and a mix of anaerobic and aerobic processes
(3) improvements to rural living conditions
(4) thorough management of soil erosion, encompassing soil- and water-conserving forests, slope transformation ladder initiatives, slope runoff management, and suitable agricultural practices

Kumar et al. (2021) highlighted biological remediation, using naturally occurring organisms like plants, bacteria, and fungi, as an affordable technique to eliminate or neutralize water contaminants and break down dangerous materials into less toxic forms. Bioremediation is typically used to remove agricultural pollutants and human sewage seeping into groundwater. Reducing chemical application to land is a main component of watershed management, replacing chemical fertilizers, antibiotics, and pesticides with natural alternatives, which significantly reduces pollutants entering the water system (Kumar et al., 2021; Wang et al., 2021). This minimizes the risk of harmful algal blooms, antibiotic resistance, and aquatic life toxicity. Eco-friendly methods often encourage biodiversity by creating more natural habitats for beneficial insects and organisms. Cover crops, through their root systems holding soil particles and leaves absorbing raindrop impact, reduce soil erosion, a major carrier of pollutants like fertilizers, pesticides, and manure into waterways (Kumar et al., 2021).

Conclusion

Water contamination from livestock production, driven by chemical use, animal waste, and agricultural runoff, poses a severe threat to water quality and ecosystem health. The presence of pesticides, heavy metals, and excess nutrients directly harms livestock, leading to reduced growth, illness, and mortality, while aquatic environments suffer from algal blooms, ecosystem disruption, and toxin accumulation. Although mitigation strategies such as improved waste management, eco-friendly alternatives, cover cropping, and precise farming offer promising solutions, their efficacy is often hampered by limited water supplies and inadequate treatment infrastructure. Addressing this escalating crisis necessitates immediate and concerted action, including robust governance, substantial investment in infrastructure, increased funding, and unwavering cooperation to ensure the sustainability of water resources and the livestock that depend on them. It is important to acknowledge that this systematic review's findings may be limited by the restricted number of search databases and the exclusion of non-English language publications, potentially impacting the generalizability and scope of the review.

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Authors' Contributions

Marothi Vincent Sebela: Was responsible for the conceptualization of the study. Along with the Khetho Ratshilumela Nemutandani, both authors significantly contributed to the design of the study. Furthermore, Marothi Vincent Sebela took the lead in formal analysis and writing the original draft.

Khetho Ratshilumela Nemutandani: As the supervisor, he provided comprehensive guidance and evaluation throughout the research phase. His involvement included contributing valuable resources and extensively reviewing and revising the manuscript to ensure its accuracy and completeness. All authors read and approved of the final manuscript.

Ethics

The authors considered critical issues such as ethics, informed consent, plagiarism, and data fabrication.

This systematic review synthesizes existing published research and does not involve the collection of new primary data from human or animal subjects. Therefore, it adheres to ethical principles of academic integrity, including proper citation of sources and avoidance of plagiarism. All authors have considered potential conflicts of interest and have none to declare.

Conflict of Interest

Authors declare that no conflict of interest was encountered concerning publication of this manuscript.

Availability of Data

Data supporting this study are available from the corresponding author upon request.

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