

# Environmental Impact Assessment of Abattoir Wastewater

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**Abstract.** Abattoir wastewater, generated during the slaughter process, contains a complex mixture of pollutants that pose significant environmental and public health risks. These pollutants include organic matter, nutrients such as nitrogen and phosphorus, pathogenic microorganisms, heavy metals, and antibiotics, which can lead to surface and groundwater contamination, soil degradation, and adverse impacts on aquatic ecosystems. This review aims to provide an overview of the composition and characteristics of abattoir wastewater, highlighting its significant environmental challenges. The paper also examines Environmental Impact Assessment (EIA) methodologies for assessing and managing these risks, with a focus on wastewater treatment practices. Researchers discuss both traditional and advanced treatment methods, highlighting their effectiveness while also identifying the gaps and limitations they present. Case studies from various countries, including Nigeria, India, Brazil, the European Union, and the USA, are reviewed to illustrate both successes and challenges in wastewater management practices. The paper explores sustainable and eco-friendly solutions, including circular economy approaches, zero liquid discharge systems, and waste-to-energy models. This study outlines research gaps, future directions, and policy recommendations, emphasising the need for integrated treatment systems, real-time monitoring, and greater community engagement in wastewater management.

**Keywords:** Abattoir wastewater; Environmental Impact Assessment; wastewater treatment; biogas production; sustainable solutions; wastewater management; heavy metals.

## INTRODUCTION

The global demand for animal protein has led to a significant increase in meat production, positioning abattoirs as pivotal components in the food

processing industry. These facilities are responsible for the slaughtering and initial livestock processing, ensuring that meat products meet health and safety standards before reaching consumers. Slaughterhouse activities play a vital role in meat

production; however, they generate substantial amounts of organic waste that can cause significant environmental harm if not properly managed and disposed of. The liquid waste typically contains suspended particles, blood, digestive tract contents, urine, fats, and water, whereas the solid waste includes leftover meat, bones, and animal excreta [42].

However, the operations within abattoirs generate substantial quantities of wastewater, which, if not properly managed, can pose severe environmental and public health risks. Abattoir wastewater is characterised by a high organic load, including blood, fat, manure, and other animal byproducts. This effluent often contains elevated levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and pathogenic microorganisms. When discharged untreated into the environment, such wastewater can contaminate surface and groundwater sources, degrade soil quality, and contribute to the proliferation of waterborne diseases [1]. In Nigeria, studies have highlighted the detrimental effects of abattoir effluents on water bodies, noting significant deviations from acceptable water quality standards [2].

The environmental implications of abattoir wastewater are multifaceted. Contaminated water bodies can lead to the eutrophication of aquatic ecosystems, resulting in the depletion of dissolved oxygen and the subsequent death of marine organisms. Additionally, the infiltration of pollutants into groundwater sources can compromise the quality of drinking water, posing health risks to surrounding communities. Soil contamination from abattoir waste can also impair agricultural productivity by altering soil pH and introducing harmful pathogens [3].

Given these concerns, conducting Environmental Impact Assessments (EIAs) becomes imperative. EIAs serve as systematic processes that evaluate the potential environmental consequences of proposed projects or activities. In the context of abattoirs, EIAs can identify the extent of ecological degradation caused by wastewater discharge and recommend mitigation strategies to minimise adverse effects. Implementing effective wastewater treatment solutions, such as anaerobic digestion, constructed wetlands, and biofiltration systems, can significantly reduce the environmental impacts of abattoir wastewater. This review aims to analyse the environmental impacts of abattoir wastewater and explore ways to reduce the

ecological footprint of abattoir operations [4]. The study's objectives include examining the composition and characteristics of abattoir wastewater, assessing the environmental and public health risks associated with untreated effluent discharge, and evaluating current wastewater treatment methods. It also seeks to identify challenges in wastewater management and propose sustainable solutions alongside policy recommendations to mitigate environmental harm. Reviewing existing literature and case studies, this review aims to raise awareness among stakeholders, including policymakers, environmental agencies, and abattoir operators, about the critical need for proper wastewater management and the adoption of sustainable practices in the meat processing industry.

*Composition and Characteristics of Abattoir Wastewater.* Abattoirs are known for producing high volumes of wastewater due to the nature of their operations, which involve animal slaughter, blood drainage, hide and offal washing, carcass processing, and facility cleaning. Many human activities contribute to the contamination of this wastewater, posing a threat to public health and the environment. The composition of abattoir wastewater is heterogeneous, typically comprising organic and inorganic substances, nutrients, microbial contaminants, heavy metals, and pharmaceutical residues, especially from antibiotics [2, 5]. The organic content in abattoir wastewater primarily originates from animal body fluids and tissues, including blood, fat, faeces, urine, and undigested feed [6]. Blood alone contains about 17% protein, and its decomposition significantly contributes to the effluent's biological oxygen demand (BOD). Fat and tissue remnants increase the oil and grease content, making the wastewater viscous and challenging to treat [7]. Animal waste, including faeces and urine, also introduces a broad spectrum of biodegradable materials that enhance microbial growth and rapidly deteriorate water quality if left untreated [8]. These organic pollutants are responsible for the high BOD and chemical oxygen demand (COD) values often recorded in slaughterhouse effluents. Reported BOD values typically range from 1,500 to over 6,000 mg/l, while COD values may exceed 8,000 mg/l, far above permissible discharge limits [9].

The nutrient load, particularly nitrogen and phosphorus, is also of grave concern. These nutrients stem mainly from excreta, blood, and undigested food in the gastrointestinal tract. In untreated wastewater, total nitrogen concentrations may range from 50 to 850 mg/L, and total phosphorus

can range from 30 to 200 mg/L [10]. High concentrations of nutrients, such as nitrogen and phosphorus, contribute to eutrophication in receiving water bodies, which promotes algal blooms and eventually depletes dissolved oxygen, thereby adversely affecting aquatic life. [11]. Excess nitrogen in the form of ammonia is also toxic to fish and other marine organisms, while phosphorus stimulates excessive plant growth that can disrupt natural water ecosystems [12]. Abattoir wastewater is also rich in pathogenic microorganisms, which makes it a significant vector of infectious diseases when released untreated. The microbial composition often includes *Escherichia coli*, *Salmonella* spp., *Clostridium perfringens*, *Shigella* spp., and *Staphylococcus aureus*, all of which originate from animal intestines and faeces [7, 13]. These bacteria are indicators of faecal contamination and can cause waterborne diseases if the wastewater contaminates drinking water sources or is used for irrigation. In many developing countries, untreated or poorly treated abattoir wastewater is discharged directly into nearby streams and rivers, posing a significant public health threat, particularly in peri-urban and rural communities [2, 10].

In large-scale and commercial abattoirs, the presence of heavy metals and antibiotic residues further complicates the environmental impact of the wastewater. Heavy metals such as copper (Cu), zinc (Zn), lead (Pb), iron (Fe), and cadmium (Cd) may originate from animal feed additives, veterinary drugs, and equipment corrosion [8]. The improper disposal of such wastewater can lead to the bioaccumulation of toxic metals in plants and aquatic organisms, posing long-term ecological risks. Moreover, residues of antibiotics used in livestock farming, such as tetracyclines, sulfonamides, and macrolides, have been detected in abattoir effluents, raising concerns about the development of antibiotic-resistant bacteria [13]. These resistant microbes can persist in aquatic environments, potentially transferring resistance genes to other bacteria through horizontal gene transfer, exacerbating the global antimicrobial resistance (AMR) crisis.

Various physicochemical parameters are routinely measured to quantify and monitor the pollution load of abattoir wastewater. The most common indicators include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), pH, and temperature. BOD and COD are critical in evaluating the efficiency of wastewater's organic strength and biological

treatment systems. Abattoir wastewater BOD levels are often 10 to 20 times higher than those of domestic sewage, indicating a high organic loading [12]. TSS values in such wastewater may range from 200 to 3,000 mg/l, reflecting the large number of suspended particles from blood clots, fats, and tissue fragments. TDS values, typically ranging from 1,000 to 4,000 mg/L, represent the wastewater's mineral content and ionic strength, which in turn influence its salinity and conductivity [6, 8].

The pH of abattoir wastewater is typically alkaline due to the presence of protein degradation products and detergents used in cleaning [10]. Values can range from 6.4 to 9.8, depending on the process and time of sampling. Additionally, temperature influences biological processes in treatment systems and natural water bodies. Abattoir effluents often exhibit elevated temperatures (28–35°C), especially in tropical regions, which may accelerate microbial activity and reduce dissolved oxygen availability in receiving waters [11].

Understanding the composition and characteristics of abattoir wastewater is fundamental for developing effective treatment strategies and conducting environmental impact assessments. The high organic and nutrient loads, microbial pathogens, and emerging contaminants, such as antibiotics, underscore the urgent need for comprehensive regulatory frameworks and sustainable wastewater management technologies. Without proper treatment, abattoir effluents can significantly contribute to the degradation of aquatic ecosystems, groundwater contamination, and public health risks in both rural and urban settings.

## RESULTS AND DISCUSSION

*Environmental Impacts of Abattoir Wastewater.* The indiscriminate discharge of untreated or poorly treated abattoir wastewater into the environment poses significant ecological and public health threats. One of the most critical concerns is the contamination of surface and groundwater resources. Abattoir effluents, typically rich in organic matter, nitrogenous compounds, pathogens, and heavy metals, can leach into nearby streams, rivers, and aquifers, particularly in regions lacking proper containment infrastructure [10, 12]. The infiltration of nitrates and ammonia into groundwater can lead to methemoglobinemia (blue baby syndrome) in infants. At the same time, surface water contamination contributes to oxygen

depletion, water turbidity, and odour problems [6]. Rivers and lakes receiving untreated slaughterhouse effluents often suffer from eutrophication, characterised by excessive algae growth, reduced biodiversity, and fish kills due to hypoxic conditions [11].

Researchers commonly observe soil degradation and loss of fertility near abattoir sites. The continuous deposition of nutrient-laden wastewater, especially without regulated treatment, accumulates nitrogen, phosphorus, fats, and suspended solids in the soil matrix [7]; this may increase nutrient content initially, but prolonged exposure disrupts soil structure, reduces aeration and alters microbial communities, resulting in poor crop yield and reduced arability. Heavy metals, such as cadmium, lead, and chromium, often introduced through animal feed additives and veterinary drugs, persist in the soil and can potentially enter the food chain through plant uptake [8]. These non-biodegradable metals may impair enzymatic functions in soil microbes, stunting plant growth and further degrading the land's agricultural potential [14].

In addition to water and soil contamination, abattoir wastewater significantly contributes to air pollution, especially in urban and peri-urban areas. The decay of organic matter, including blood, tissues, fats, and offal, generates offensive odours and releases gaseous pollutants such as methane ( $\text{CH}_4$ ), ammonia ( $\text{NH}_3$ ), and hydrogen sulfide ( $\text{H}_2\text{S}$ ) [2]. These gases are unpleasant and harmful to human and animal health. Hydrogen sulfide, for instance, is a potent neurotoxin at high concentrations, while ammonia can cause respiratory irritation. Methane, a byproduct of anaerobic decomposition, is a potent greenhouse gas with over 25 times the global warming potential of carbon dioxide over a 100-year period [15]. Inadequate waste handling and the accumulation of stagnant wastewater around slaughter facilities can also attract pests such as flies, rodents, and stray animals, creating unsanitary conditions that exacerbate disease transmission.

One of the most alarming impacts of abattoir wastewater is its potential to elevate public health risks, primarily through the spread of pathogenic bacteria and antimicrobial resistance. Numerous studies have detected pathogenic organisms, such as *Salmonella* spp., *E. coli*, *Clostridium perfringens*, and *Shigella* spp., in abattoir effluents [5, 13]. Suppose such effluents are discharging into open drains or water bodies used for

drinking, bathing, or irrigation. In that case, they may be transmission pathways for gastrointestinal infections, skin diseases, and enteric fevers. Additionally, antibiotic residues and antibiotic-resistant bacteria in wastewater from commercial livestock facilities introduce another layer of concern. These microbes can survive wastewater treatment processes and persist in the environment, where they can transfer resistance genes to native bacterial populations, fueling the global antimicrobial resistance crisis [16]. This issue is particularly worrisome in developing countries where regulatory oversight and wastewater treatment infrastructures are weak or non-existent.

Lastly, the impact of abattoir effluents on aquatic ecosystems cannot be overstated. The direct discharge of organic-rich effluents into rivers and lakes leads to oxygen depletion through microbial decomposition, resulting in the suffocation and death of aquatic organisms, particularly fish and benthic invertebrates [12]. The rise in nutrient levels further alters the ecological balance of water bodies by promoting algal blooms, which reduce light penetration, disrupt photosynthesis, and reduce biodiversity. Moreover, heavy metals and antibiotic residues can bioaccumulate in aquatic organisms, posing long-term ecological risks and public health concerns, particularly for communities that depend on these water sources for food and livelihood [10, 11]. Over time, these disturbances can lead to irreversible changes in ecosystem structure and function, threatening the sustainability of local fisheries and wetland ecosystems.

Abattoir wastewater presents a multifaceted environmental challenge with far-reaching consequences. From contaminating water and degrading soil to polluting air and endangering public health, the impacts of poorly managed slaughterhouse effluents underscore the urgent need for comprehensive waste management strategies, stricter environmental regulations, and the deployment of sustainable treatment technologies. Without timely intervention, these pollutants will continue to threaten ecosystem integrity and compromise the health and well-being of human and animal populations.

*Methodologies Used in Environmental Impact Assessment (EIA) for Abattoirs.* Environmental Impact Assessment (EIA) is a crucial tool for evaluating the potential environmental impacts of abattoir activities before they are implemented. Given the complexity of ecological interactions

associated with slaughterhouse operations, a multidisciplinary approach is employed to ensure a comprehensive assessment of these interactions. Methodologies commonly used in EIA for abattoirs include site assessment, sampling and analysis, risk evaluation, modelling techniques, and stakeholder engagement, each contributing essential data to guide decision-making and mitigation strategies.

The first step in EIA is site assessment and baseline environmental studies, which involve collecting pre-project environmental data on land use, hydrology, air quality, vegetation, biodiversity, and the proposed site's socio-economic context [17]. Baseline data help determine the site's sensitivity to future impacts and establishes reference points for future monitoring. Parameters such as existing groundwater quality, proximity to residential or agricultural zones, and soil structure are assessed through field surveys, satellite imagery, and Geographic Information Systems (GIS) [18]. In the context of abattoirs, particular attention is given to water bodies near the site, as these are often the most vulnerable to effluent contamination. Following baseline studies, sampling and laboratory analysis form the empirical core of the EIA process. These methods involve collecting water, soil, and air samples in and around the abattoir to measure various pollutants. Typical parameters include Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pH, temperature, nutrient concentrations (e.g., nitrates, phosphates), heavy metals (e.g., cadmium, chromium, lead), and microbial contaminants such as *E. coli* and *Salmonella* [2, 10]. Sampling adheres to the standards established by environmental agencies, such as the American Public Health Association (APHA), to ensure consistency and accuracy. Laboratory results provide quantifiable evidence of environmental pollution, enabling the determination of compliance with environmental standards. Another key methodology is risk and hazard analysis, which assesses the likelihood and severity of environmental and health hazards posed by abattoir operations. Risk matrices, hazard indices, and scenario-based analysis identify potential accidents (e.g., chemical spills, effluent overflows) and consequences [19]. This step also evaluates human health risks, especially exposure to pathogens and antibiotic-resistant organisms. Health risk assessments may include dose-response relationships, exposure modelling, and comparison of

contaminant levels to threshold limit values. The outcomes of this analysis guide the development of mitigation measures and emergency response strategies.

In many modern EIA procedures, predictive modelling forecasts potential environmental impacts under different operational or waste management scenarios. Models such as AQUATOX, MODFLOW, or SWAT can simulate how effluents will move through water systems, accumulate in the soil, or affect biota over time [8]. For example, hydrological models can predict the dispersion of contaminants in rivers or aquifers, while air dispersion models estimate how odours or gas emissions might affect nearby communities. Predictive models are beneficial for understanding long-term impacts, assessing cumulative effects, and testing the effectiveness of proposed mitigation strategies.

Finally, stakeholder engagement and social impact assessment are essential to EIA, especially where abattoir operations intersect with local communities. Stakeholder engagement involves public consultations, community surveys, and participatory meetings with residents, farmers, health officials, and regulatory bodies [17]. These activities aim to understand community concerns, gather Indigenous knowledge, and promote transparency in decision-making. Social impact assessment evaluates the impact of abattoir projects on livelihoods, land use, cultural heritage, and public health. Effective stakeholder engagement improves the quality of the EIA, helps prevent social conflicts, and promotes community acceptance of mitigation plans.

The EIA of abattoirs requires interconnected methodologies that comprehensively understand environmental and social risks. From physical site assessments and pollutant analysis to risk modelling and community engagement, each step plays a vital role in ensuring that abattoir operations are conducted in an environmentally sustainable and socially responsible manner. Implementing robust EIA frameworks is particularly crucial in developing countries, where regulatory enforcement is often weak and environmental degradation can have severe consequences for both ecosystems and human health.

*Current Wastewater Treatment Practices.* Effective abattoir wastewater treatment is crucial to mitigate its adverse environmental and public health impacts. Due to the complex composition of abattoir effluents, which comprises high

organic loads, nutrients, pathogenic microorganisms, and occasional heavy metals, multiple treatment strategies have been developed and employed globally. These strategies range from conventional physical and biological methods to advanced and hybrid technologies, each with varying efficiency, cost implications, and sustainability. This section discusses the primary treatment methods, evaluates their effectiveness, and highlights the existing gaps and limitations.

**1) Conventional Treatment Methods.** Conventional treatment methods remain the most widely used in developing regions due to their low operational costs and technical simplicity. Engineers primarily design these systems—including sedimentation tanks, anaerobic lagoons, and trickling filters—to reduce organic matter, suspended solids, and, to some extent, pathogenic loads. Sedimentation is often the first step in the treatment process. It allows heavier solids such as faeces, fats, and undigested feed particles to settle at the bottom of a tank or basin [4]. Although cost-effective and straightforward, this method is largely ineffective in removing dissolved pollutants such as ammonia, phosphates, and microbial contaminants. Anaerobic lagoons are frequently used for primary or secondary treatment, leveraging the action of anaerobic bacteria to degrade organic matter under oxygen-free conditions. These systems are well-suited for abattoirs because they can handle high organic loading rates [20]. However, they often release methane and hydrogen sulfide gases, contributing to greenhouse gas emissions and odours if not properly managed.

Trickling filters, another common technique, use a bed of coarse media (e.g., stones or plastic) on which microbial films grow. These microbes break down organic pollutants as wastewater trickles over the press [21]. While effective in reducing biochemical oxygen demand (BOD) and certain pathogens, trickling filters may clog over time and are less efficient in handling high volumes or sudden increases in waste.

**2) Advanced Treatment Technologies.** Advanced wastewater treatment technologies have been developed to address the limitations of conventional systems. These methods offer improved pollutant removal efficiencies and are often more compact and automated, although they come with higher capital and maintenance costs.

One notable approach is the membrane bioreactor (MBR), which integrates biological treatment with membrane filtration. MBRs effectively

remove BOD, COD, suspended solids, and pathogens [22]. The membranes act as a physical barrier, ensuring the production of high-quality effluent. Despite their performance, MBRs require regular membrane cleaning and replacement, making them cost-prohibitive for small-scale abattoirs. Constructed wetlands (CWs) provide a nature-based, sustainable alternative to treating abattoir wastewater. These systems mimic natural wetlands using vegetation, soil, and microbial communities to filter and degrade pollutants. CWs effectively remove nutrients, such as nitrogen and phosphorus, and are particularly suited for rural and peri-urban areas [23]. However, climate, plant health, and hydraulic loading rates can influence their seasonal performance.

Another promising technique is electrocoagulation, which uses an electric current to destabilise and remove suspended, colloidal, and dissolved contaminants. This method has shown excellent results in reducing turbidity, BOD, and heavy metals in industrial effluents [24]. Nonetheless, the technology is energy-intensive and requires skilled personnel to operate and monitor it effectively.

**3) Effectiveness and Comparative Analysis.** The effectiveness of each treatment method varies depending on influent characteristics, system design, and operational conditions. Conventional systems, such as anaerobic lagoons, are adept at handling large volumes and reducing organic matter, but are less efficient at removing nutrients and pathogens. In contrast, advanced systems such as MBRs and electrocoagulation provide superior effluent quality, but at higher costs and with more stringent technical requirements. Studies have shown that combining multiple treatment methods in a hybrid system can enhance efficiency. For example, integrating anaerobic digestion with constructed wetlands or membrane filtration can achieve comprehensive treatment, targeting organic and inorganic pollutants [25]. Such integrated systems are becoming increasingly popular in regions with stricter environmental regulations or limited space.

Despite the advancements, several gaps and limitations persist in abattoir wastewater treatment. One major challenge is the lack of standardised treatment guidelines tailored to abattoirs, especially in low and middle-income countries. Many facilities operate without proper wastewater management infrastructure, discharging untreated or partially treated effluents into the

environment [2]. Additionally, economic and technical barriers hinder the adoption of advanced technologies. Many small and medium-sized slaughterhouses lack the financial capacity or technical expertise to implement high-tech solutions.

Furthermore, regular maintenance and skilled labour are often unavailable, resulting in system failure or underperformance. Another concern is the limited monitoring and enforcement of effluent discharge standards. Even when treatment facilities are available, poor oversight and weak institutional frameworks often result in non-compliance. Lastly, conventional systems do not effectively remove emerging contaminants such as antibiotic residues and hormones and remain under-researched in many regions [26].

While various treatment technologies exist to address the challenges of abattoir wastewater, no single method is universally optimal. A context-specific, integrated approach considering environmental, economic, and social dimensions is essential for sustainable wastewater management in the meat processing industry.

**4) Case Studies from Different Countries.** Abattoir wastewater management and Environmental Impact Assessment (EIA) practices vary significantly across regions due to differences in regulatory frameworks, technological capabilities, economic priorities, and variations in institutional enforcement. Understanding how various countries handle abattoir waste helps identify global best practices, lessons learned, and challenges to guide future sustainable slaughterhouse operations. Below is a comparative analysis of selected countries and regions, showcasing their experiences with abattoir waste management and EIA implementation.

*Nigeria/Sub-Saharan Africa.* In Nigeria and much of Sub-Saharan Africa, abattoir waste management remains informal and under-regulated. Many slaughterhouses discharge untreated or partially treated effluents directly into open drains, water bodies, or surrounding lands, contributing to severe environmental degradation and public health risks [2]. Environmental Impact Assessments are often poorly enforced or completely absent, especially in rural and peri-urban areas where small-scale abattoirs operate without official oversight [27]. While efforts are underway to introduce cleaner practices, such as pilot biodigester installations and constructed wetlands in some states, success is limited due to poor

maintenance, a lack of technical expertise, and inadequate funding. Community engagement is often minimal, and regulatory institutions struggle to effectively monitor compliance.

*India.* India faces similar challenges in Sub-Saharan Africa, but has made notable progress in recent years. The Central Pollution Control Board (CPCB) mandates proper EIA documentation and treatment of slaughterhouse effluents, particularly in urban areas [28]. Large abattoirs are required to install effluent treatment plants (ETPs), and there is a growing adoption of anaerobic digesters and biogas recovery systems. However, small and medium enterprises still struggle with compliance, citing high costs and a lack of incentives. Some government initiatives have sought to link biogas generation to energy supply, promoting waste-to-energy schemes that encourage proper waste handling [29]. Nevertheless, enforcement remains inconsistent, and the informal meat sector remains a significant environmental concern.

*Brazil.* Brazil, one of the world's largest meat exporters, maintains stricter regulations on abattoir wastewater management. The National Environmental Council (CONAMA) provides clear guidelines for waste treatment and discharge limits. Most large-scale slaughterhouses employ advanced treatment systems, including activated sludge processes, anaerobic lagoons, and constructed wetlands [30]. Brazil has also invested in reusing treated water for cleaning, irrigation, and nutrient recovery for fertiliser production. Environmental licensing and EIA procedures are well-developed, especially for export-oriented facilities. However, some small rural abattoirs still operate informally without proper waste disposal systems, often due to gaps in local enforcement mechanisms.

*European Union (EU) Countries.* The EU has some of the most advanced and harmonised standards for abattoir waste management, governed by directives such as the Urban Wastewater Treatment Directive (91/271/EEC) and Animal Byproducts Regulation (EC No 1069/2009). All abattoirs must perform comprehensive EIAs before commissioning and follow strict effluent treatment and environmental monitoring protocols.

Countries such as Germany, the Netherlands, and Denmark implement integrated treatment systems, which combine physical, chemical, and biological processes. Technologies such as membrane bioreactors, nitrification-denitrification

systems, and energy recovery units are now standard. Public participation and stakeholder engagement are required components of EIA processes, ensuring transparency and sustainability [31].

*United States of America (USA).* The USA enforces abattoir waste management through agencies like the Environmental Protection Agency (EPA) and state-level bodies. The Clean Water Act (CWA) mandates that all point source discharges from meat processing facilities comply with National Pollutant Discharge Elimination System (NPDES) permits.

Most facilities employ multi-stage wastewater treatment systems, which typically include screening, dissolved air flotation, anaerobic digestion, and tertiary filtration. EIA requirements vary by state; however, extensive facilities are required to conduct environmental assessments and public consultations under the National Environmental

Policy Act (NEPA). Advanced monitoring systems and compliance audits ensure that environmental standards are consistently met [32].

**5) Sustainable and Eco-Friendly Solutions.** The rapid industrialisation of abattoirs has brought about challenges related to the large volumes of wastewater generated during slaughter. Traditional wastewater disposal methods often result in significant environmental harm, particularly when effluent is discharged without proper treatment. Therefore, innovative, sustainable, and eco-friendly solutions are crucial for managing abattoir wastewater in a manner that minimises environmental impact, reduces waste, and contributes positively to energy production and resource recovery. This section explores several approaches, including the circular economy model, zero liquid discharge systems, waste-to-energy models, community-led Management, and policy interventions.

Table 1 – Abattoir Wastewater Management and EIA Practices

Country/Region	EIA Enforcement	Treatment Technologies	Key Strengths	Key Challenges
Nigeria/Sub-Saharan Africa	Weak	Sedimentation pits, informal drainage	Low-cost solutions, community initiatives	Poor enforcement, lack of infrastructure
India	Moderate	Anaerobic digestion, ETPs	Government incentives, growing biogas use	High cost for SMEs, weak informal sector oversight
Brazil	Strong	Activated sludge, anaerobic lagoons	Nutrient recovery, water reuse	Informal rural operations
European Union	Very Strong	MBR, nitrification, energy recovery	Stringent laws, advanced technologies	High costs, stringent compliance burden
USA	Strong	Multi-stage (DAF, digestion, filtration)	Strong regulatory monitoring and audits	Varying state-level EIA requirements

*Circular Economy Approach (e.g., Biogas Production).* The circular economy concept offers a sustainable paradigm by focusing on the recovery and reuse of resources rather than their disposal. In the context of abattoir wastewater, one of the most promising circular solutions is biogas production through anaerobic digestion. Abattoir waste is rich in organic matter, including blood, fat, undigested feed, and other residuals, which can serve as substrates for biogas generation.

Biogas production helps reduce the environmental footprint of abattoir wastewater and offers a

renewable energy source. According to authors [33], anaerobic digesters can convert organic waste into methane gas, which can be used for heating, electricity generation, or as a fuel source for other operations within the facility. The digestion process also produces a solid byproduct called digestate, which can be used as a nutrient-rich fertiliser. This recovery of energy and nutrients transforms abattoir wastewater into a resource rather than a pollutant, promoting a closed-loop system that supports the principles of the circular economy. Moreover, biogas systems contribute to reducing greenhouse gas emissions,

particularly methane, a potent greenhouse gas. The application of biogas production in slaughterhouses is gaining traction, particularly in countries such as Germany and the United States, where waste-to-energy systems are integrated into industrial operations [34]. However, while biogas production presents a viable solution, challenges remain regarding initial investment costs and the scaling of systems for small and medium-sized facilities [33].

*Zero Liquid Discharge (ZLD) Systems.* Another advanced sustainable solution for abattoir wastewater management is Zero Liquid Discharge (ZLD) systems. ZLD systems recover all the water from the wastewater stream, leaving only solid waste that operators can safely dispose of or repurpose. The primary goal of ZLD is to reduce the environmental footprint of wastewater effluent by ensuring that no liquid waste is discharged into the environment. ZLD systems typically include a combination of physical, chemical, and biological treatment processes such as reverse osmosis, evaporation, and crystallisation. These technologies remove contaminants, including salts, heavy metals, and organic pollutants, making the effluent suitable for reuse [35]. For abattoirs, ZLD systems provide a solution to water scarcity by allowing treated water to be recycled for use in cleaning, irrigation, or even within the production process itself. The implementation of ZLD, however, can be costly in terms of capital expenditure, and its adoption often depends on local regulatory frameworks, concerns about water scarcity, and the scale of the slaughterhouse operation. Authors [36] pointed out that while ZLD provides an environmentally sound alternative to conventional disposal methods, its high operational costs and energy consumption remain significant barriers to widespread implementation, especially in developing countries. Nonetheless, in water-scarce regions, such as parts of the Middle East and Africa, ZLD remains a promising solution [35].

*Waste to Energy Models.* Incorporating waste-to-energy (WTE) technologies into abattoir wastewater management presents a promising strategy for generating renewable energy while addressing the challenges of wastewater disposal. WTE technologies involve converting solid waste into usable energy, such as electricity or heat, through incineration, pyrolysis, or gasification [37]. These technologies are especially relevant to larger abattoirs that generate significant amounts of organic waste, which can be burned or

processed to produce energy. In addition to reducing the need for external energy sources, WTE systems help mitigate air pollution and greenhouse gas emissions by controlling the release of harmful substances that would otherwise result from the decomposition of organic waste in landfills [37]. For example, pyrolysis converts organic waste into syngas, and operators can burn it to produce heat or electricity while reducing the waste volume.

Although WTE technologies have proven successful in large-scale facilities, they come with limitations, such as high setup and operational costs, as well as the need for a continuous supply of organic waste to ensure energy generation [37]. Moreover, the emission of certain pollutants, like dioxins and furans, requires stringent controls to ensure compliance with environmental standards. Nonetheless, WTE technologies effectively deal with abattoir wastewater while contributing to energy security and reducing reliance on fossil fuels.

*Community-led monitoring and Management of abattoir wastewater* can ensure environmental sustainability in low- and middle-income countries with weak regulatory frameworks. This approach involves engaging local communities in overseeing and managing wastewater treatment processes, increasing accountability and encouraging sustainable practices. Community-led initiatives empower local stakeholders to participate actively in the monitoring and management of wastewater quality. For instance, community members can be trained to monitor water quality, detect illegal discharges, and advocate for sustainable waste management practices [38]. Such initiatives can also allow community members to learn about the health and environmental risks associated with improper wastewater management, thereby fostering more responsible behaviours.

In Kenya and Ghana, participatory governance models have successfully created effective local-level waste management systems. These systems are more sustainable, culturally appropriate, and adaptable to local needs. By involving communities in the management process, these programs promote environmental stewardship and build public trust, which is essential for long-term sustainability efforts [39].

*Policy Interventions.* Lastly, policy interventions are crucial in driving sustainable practices in abattoir wastewater management. Governments and international organisations can incentivise

sustainable waste management practices through financial support, regulations, and enforcement. For example, governments can provide subsidies or tax breaks to encourage the installation of biogas systems or zero-liquid discharge technologies [11]. Additionally, implementing penalties for facilities that fail to meet environmental standards can promote compliance and discourage illegal discharge practices. Another critical policy intervention is the introduction of mandatory Environmental Impact Assessments (EIA) for all new or expanded abattoirs. These assessments help identify potential environmental impacts and implement appropriate mitigation measures during the planning phase.

Furthermore, national and international regulations that establish clear standards for wastewater treatment and waste disposal are essential for maintaining high environmental quality standards across the sector. While policy interventions are vital, enforcement remains a challenge in many regions. Strengthening regulatory frameworks, ensuring adequate monitoring systems, and increasing public participation are crucial to making policies more effective and ensuring that abattoirs adhere to sustainable practices [40].

**6) Future Directions.** Despite the growing recognition of the environmental and public health risks associated with abattoir wastewater, substantial gaps remain in research and practical implementation of sustainable solutions. As abattoirs continue to expand globally, particularly in developing nations, there is an urgent need for more comprehensive research into integrated treatment systems, real-time monitoring technologies, and community involvement. Addressing these gaps will be crucial in advancing the efficiency of wastewater management practices and reducing the environmental footprint of the meat processing industry.

*Need for Integrated Treatment Systems.* Integrating treatment systems is one of the most pressing research gaps in abattoir wastewater management. Traditional wastewater treatment processes, such as sedimentation and anaerobic digestion, are often used in isolation, which may not effectively address the full spectrum of pollutants in abattoir effluents. There is a need for integrated, multi-barrier systems that combine biological, chemical, and physical treatments to achieve high-efficiency results. Recent studies suggest that combined treatment systems, such as

integrating membrane bioreactors (MBRs) with constructed wetlands or anaerobic digestion with reverse osmosis hold promise for significantly improving the treatment process [35]. These hybrid systems can optimise the removal of key contaminants such as pathogenic microorganisms, nutrient loads (e.g., nitrogen and phosphorus), and organic matter [34]. However, research is needed to evaluate the cost-effectiveness, scalability, and long-term viability of these integrated solutions, especially for smaller abattoirs. Moreover, integrating wastewater recovery technologies with waste-to-energy systems can help abattoirs manage their wastewater and turn it into a valuable resource. Biogas production from organic waste can serve as a renewable energy source for abattoir operations, thus making the wastewater treatment process both eco-friendly and economically sustainable [33]. However, further research is still required to explore optimal designs for integrating these systems and ensuring their sustainability in the context of varying scales and waste compositions across different types of abattoirs.

*Role of IoT and Real-Time Monitoring.* Another emerging area that requires further investigation is the role of the Internet of Things (IoT) and real-time monitoring in enhancing the management of abattoir wastewater. Integrating IoT devices into wastewater treatment plants enables continuous, automated monitoring of critical parameters, including BOD, COD, pH, temperature, and turbidity. Real-time monitoring technologies can detect irregularities in effluent quality before they reach harmful levels, allowing operators to make immediate adjustments and reduce the risk of non-compliance with environmental standards [41].

IoT-based systems can also aid in tracking and managing wastewater flows, energy consumption, and chemical usage, thereby enhancing the overall efficiency of treatment processes. However, while there have been promising advances in this area, research into the practical application of IoT solutions in abattoir wastewater management is still in its early stages. Key challenges include sensor calibration, data interoperability, and system integration [41]. Future studies should explore the feasibility of implementing cost-effective IoT solutions in both large-scale and small-scale slaughterhouses, as well as developing robust data analytics tools to interpret sensor data collected.

*Community Awareness and Involvement.* Research has also highlighted the need for community awareness and local involvement in wastewater management practices, especially in countries with less stringent regulations or areas lacking environmental education. Community-led initiatives can significantly improve the implementation of wastewater management strategies by fostering public accountability, encouraging sustainable practices, and empowering local stakeholders to take ownership of their environment. However, despite the importance of involving communities in waste management, there is limited research on effectively engaging and educating local populations, particularly in regions with limited access to formal education or where industrial practices may not be well-regulated. Studies in Kenya and Nigeria have shown that community-based management systems can improve compliance and waste reduction [39]. Research is needed to design effective educational programs and participation frameworks that empower local communities to monitor and report wastewater pollution, as well as participate in sustainable management practices. Moreover, research should explore the socio-economic benefits of community engagement in wastewater management, particularly in low-income areas where economic constraints may otherwise prevent the adoption of advanced technologies. Involving communities in decision-making can help develop context-specific solutions tailored to local needs and realities, ensuring better sustainability and long-term success [38].

*Policy Enforcement and Regulatory Framework.* Lastly, there is a critical need for policy enforcement and the strengthening of regulatory frameworks governing the wastewater management practices of abattoirs. Many countries, particularly in Sub-Saharan Africa and certain parts of Asia, continue to face significant challenges in enforcing environmental regulations and monitoring industrial compliance. While several nations have established national standards for wastewater treatment, compliance remains a significant issue due to a lack of resources, corruption, and limited enforcement mechanisms [40]. Future research should focus on evaluating the effectiveness of current regulatory frameworks and identifying strategies for improving enforcement and accountability in abattoir wastewater management; this could involve examining case studies from countries with successful implementation of wastewater treatment regulations, such as the European Union, and identifying best

practices that could be adopted in less developed regions.

Additionally, research into the economic incentives for abattoirs to comply with environmental standards, such as tax breaks or subsidies for adopting green technologies, could also drive positive change [11]. Research into abattoir wastewater management should prioritise the development of integrated, energy-efficient, and scalable treatment systems, adopt IoT-based real-time monitoring solutions, and strengthen community involvement and policy enforcement. These areas represent key opportunities for improving environmental sustainability and mitigating the harmful impacts of wastewater discharges from abattoirs.

## CONCLUSIONS

The environmental impact of abattoir wastewater is a pressing concern that affects not only water bodies and ecosystems but also human health and local communities. This review reveals that slaughterhouse wastewater contains numerous pollutants, including organic matter, nutrients, heavy metals, and pathogenic microorganisms. These pollutants can lead to surface and groundwater contamination, soil degradation, and public health risks if not properly managed. The Environmental Impact Assessment (EIA) plays a pivotal role in preventing such degradation by identifying potential environmental hazards and recommending appropriate mitigation measures. The review also underscores the importance of adopting sustainable and eco-friendly solutions such as biogas production, zero liquid discharge systems, and waste-to-energy technologies. These solutions offer promising alternatives to conventional treatment methods by recovering resources from wastewater and minimising waste. Moreover, policy interventions, community engagement, and research into integrated treatment systems are essential for improving the effectiveness of wastewater management and ensuring compliance with environmental regulations. Developing localised, sustainable solutions tailored to the specific needs of different regions and abattoir types is crucial. The continued advancement of wastewater treatment technologies, combined with effective regulatory frameworks and active community engagement, will significantly contribute to reducing the environmental footprint of the meat processing industry. Further research and collaboration between stakeholders,

government bodies, industrial actors, and local communities will be vital in addressing the challenges of abattoir wastewater management and

fostering a more sustainable and environmentally responsible approach to food processing.

## REFERENCES

1. Mittal, G. (2005). Treatment of wastewater from abattoirs before land application – a review. *Bioresource Technology*, 97(9), 1119–1135. doi: [10.1016/j.biortech.2004.11.021](https://doi.org/10.1016/j.biortech.2004.11.021)
2. Adelegan, J. A. (2007). *The history of environmental policy and pollution of water sources in Nigeria (1960-2004)*. Oyo State: University of Ibadan.
3. Osibanjo, N., O, N., Adie, N., & G, U. (2007). Impact of effluent from Bodija abattoir on the physico-chemical parameters of Oshunkaye stream in Ibadan City, Nigeria. *African Journal of Biotechnology*, 6(15), 1806–1811. doi: [10.5897/ajb2007.000-2266](https://doi.org/10.5897/ajb2007.000-2266)
4. Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). *Wastewater Engineering: Treatment and Reuse* (4th Ed.). McGraw-Hill.
5. Ariyo, A. B., & Obire, O. (2021). Microbiological and physicochemical characteristics of abattoir wastewaters in Bayelsa and Rivers State. *South Asian Journal of Research in Microbiology*, 32–45. doi: [10.9734/sajrm/2021/v11i130243](https://doi.org/10.9734/sajrm/2021/v11i130243)
6. Akan, J. C., Abdulrahman, F. I., & Yusuf, E. (2010). Physical and chemical parameters in abattoir wastewater sample, Maiduguri Metropolis, Nigeria. *The Pacific Journal of Science and Technology*, 11(1), 640-648.
7. Rabah, A. B., Ijah, U. J. J., Manga, S. B., & Ibrahim, M. L. (2008). Assessment of Physico-chemical and Microbiological qualities of Abattoir Wastewater in Sokoto, Nigeria. *Nigerian Journal of Basic and Applied Sciences*, 16(2), 149–154.
8. Bello, Y. O., & Oyedemi, D. T. A. (2009). The impact of abattoir activities and Management in residential neighbourhoods: a case study of Ogbomoso, Nigeria. *Journal of Social Sciences*, 19(2), 121–127. doi: [10.1080/09718923.2009.11892699](https://doi.org/10.1080/09718923.2009.11892699)
9. Bustillo-Lecompte, C., & Mehrvar, M. (2017). Slaughterhouse Wastewater: Treatment, Management and resource recovery. In *InTech eBooks*. doi: [10.5772/65499](https://doi.org/10.5772/65499)
10. Ogundiran, M. A., Fawole, O. O., Adewoye, S. O., & Ayandiran, T. A. (2010). Toxicological impact of detergent effluent on juvenile African Catfish (*Clarias Gariepinus*) (Buchell 1822). *Agriculture and Biology Journal of North America*, 1(3), 330-342.
11. Galanakis, C. M. (2019). Sustainable Meat Production and Processing. In Elsevier eBooks. doi: [10.1016/c2017-0-02230-9](https://doi.org/10.1016/c2017-0-02230-9)
12. Omole, D., & Longe, E. (2008). An assessment of the impact of abattoir effluents on River Illo, Ota, Nigeria. *Journal of Environmental Science and Technology*, 1(2), 56–64. doi: [10.3923/jest.2008.56.64](https://doi.org/10.3923/jest.2008.56.64)
13. Homeier-Bachmann, T., Heiden, S. E., Lübcke, P. K., Bachmann, L., Bohnert, J. A., Zimmermann, D., & Schaufler, K. (2021). Antibiotic-Resistant Enterobacteriaceae in wastewater of abattoirs. *Antibiotics*, 10(5), 568. doi: [10.3390/antibiotics10050568](https://doi.org/10.3390/antibiotics10050568)
14. Ogunlade, T. M., Babaniyi, B. R., & Orija, D. (2021). Microbial and Heavy Metal Analysis on Abattoir Soil. *International Journal of Environmental Planning and Management*, 7(2), 36-41.
15. EPA. (2021). *Understanding global warming potentials*. Retrieved from [https://19january2021snapshot.epa.gov/ghgemissions/understanding-global-warming-potentials\\_.html](https://19january2021snapshot.epa.gov/ghgemissions/understanding-global-warming-potentials_.html)
16. WHO. (2014). *Antimicrobial resistance: Global report on surveillance*. Retrieved from <https://www.who.int/publications/i/item/9789241564748>

17. Glasson, J., & Therivel, R. (2019). Introduction to environmental impact assessment. In *Routledge eBooks*. doi: [10.4324/9780429470738](https://doi.org/10.4324/9780429470738)
18. Oyinlola, K. A., Odujibe, F. O., Ajibare, A. O., Oriolowo, D. K., Ogunleye, G. E., Odebunmi, E. O., & Kazeem, M. O. (2023). Assessment of the impact of wastewater from an abattoir in Oyo state on groundwater in Onidundu community, Nigeria. *Agricultural Science and Technology*, *15*(2), 51–60. doi: [10.15547/ast.2023.02.016](https://doi.org/10.15547/ast.2023.02.016)
19. Bond, A., Pope, J., Morrison-Saunders, A., Retief, F., & Gunn, J. A. (2014). Impact assessment: Eroding benefits through streamlining? *Environmental Impact Assessment Review*, *45*, 46–53. doi: [10.1016/j.eiar.2013.12.002](https://doi.org/10.1016/j.eiar.2013.12.002)
20. Adewumi, J., Ilemobade, A., & Van Zyl, J. (2010). Treated wastewater reuse in South Africa: Overview, potential and challenges. *Resources Conservation and Recycling*, *55*(2), 221–231. doi: [10.1016/j.resconrec.2010.09.012](https://doi.org/10.1016/j.resconrec.2010.09.012)
21. Aslam, M., Khan, Z., Sultan, M., Niaz, Y., Mahmood, M., Shoaib, M., Shakoor, A., & Ahmad, M. (2017). Performance Evaluation of Trickling Filter-Based Wastewater Treatment System utilising cotton sticks as filter media. *Polish Journal of Environmental Studies*, *26*(5), 1955–1962. doi: [10.15244/pjoes/69443](https://doi.org/10.15244/pjoes/69443)
22. Zhang, C., Wang, G., & Hu, Z. (2014). Changes in wastewater treatment performance and activated sludge properties of a membrane bioreactor at low-temperature operation. *Environmental Science Processes & Impacts*, *16*(9), 2199–2207. doi: [10.1039/c4em00174e](https://doi.org/10.1039/c4em00174e)
23. Vymazal, J. (2010). Constructed wetlands for wastewater treatment: five decades of experience. *Environmental Science & Technology*, *45*(1), 61–69. doi: [10.1021/es101403q](https://doi.org/10.1021/es101403q)
24. Khandegar, V., & Saroha, A. K. (2013). Electrocoagulation for the treatment of textile industry effluent – A review. *Journal of Environmental Management*, *128*, 949–963. doi: [10.1016/j.jenvman.2013.06.043](https://doi.org/10.1016/j.jenvman.2013.06.043)
25. Alam, P., Khan, A. H., Américo-Pinheiro, J. H. P., & Ahmad, K. (2024). Innovative and hybrid technologies for wastewater treatment and recycling. In *CRC Press eBooks*. doi: [10.1201/9781003454199](https://doi.org/10.1201/9781003454199)
26. Parida, V. K., Saidulu, D., Majumder, A., Srivastava, A., Gupta, B., & Gupta, A. K. (2021). Emerging contaminants in wastewater: A critical review on occurrence, existing legislations, risk assessment, and sustainable treatment alternatives. *Journal of Environmental Chemical Engineering*, *9*(5), 105966. doi: [10.1016/j.jece.2021.105966](https://doi.org/10.1016/j.jece.2021.105966)
27. Elemile, O. O., Raphael, D. O., Omole, D. O., Oloruntoba, E. O., Ajayi, E. O., & Ohwavborua, N. A. (2019). Assessment of the impact of abattoir effluent on groundwater quality in a residential area of Omu-Aran, Nigeria. *Environmental Sciences Europe*, *31*(1). doi: [10.1186/s12302-019-0201-5](https://doi.org/10.1186/s12302-019-0201-5)
28. Kumar, R., Chugh, P., Goswami, M., Pathak, V., & Yadav, S. (2024). Current Status of Slaughterhouses in India. *The Science World, a monthly e-magazine*, *4*(10), 3809-3811
29. Ferdeş, M., Zăbavă, B. Ş., Paraschiv, G., Ionescu, M., Dincă, M. N., & Moiceanu, G. (2022). Food waste management for biogas production in the context of sustainable development. *Energies*, *15*(17), 6268. doi: [10.3390/en15176268](https://doi.org/10.3390/en15176268)
30. Oliveira, H. R., Kozłowsky-Suzuki, B., Björn, A., Yekta, S. S., Caetano, C. F., Pinheiro, É. F. M., Marotta, H., Bassin, J. P., Oliveira, L., De Miranda Reis, M., Schultz, M. S., Mangiavacchi, N., Ferreira-Leitão, V. S., Fasheun, D. O., Silva, F. G., Taveira, I., De França Soares Alves, I. R., Castro, J., Durão, J. V., Enrich-Prast, A. (2023). Biogas potential of biowaste: A case study in the State of Rio de Janeiro, Brazil. *Renewable Energy*, *221*, 119751. doi: [10.1016/j.renene.2023.119751](https://doi.org/10.1016/j.renene.2023.119751)
31. European Commission. (n. d.). Urban Wastewater. Retrieved from [https://environment.ec.europa.eu/topics/water/urban-wastewater\\_en](https://environment.ec.europa.eu/topics/water/urban-wastewater_en)
32. EPA. (2025). Meat and Poultry Products Effluent Guidelines. Retrieved from <https://www.epa.gov/eg/meat-and-poultry-products-effluent-guidelines>

33. Kefalew, T., & Lami, M. (2021). Biogas and bio-fertiliser production potential of abattoir waste: implication in sustainable waste management in Shashemene City, Ethiopia. *Heliyon*, 7(11), e08293. doi: [10.1016/j.heliyon.2021.e08293](https://doi.org/10.1016/j.heliyon.2021.e08293)
34. Kabeyi, M. J. B., & Olanrewaju, O. A. (2020). Optimum Biogas Production from Slaughterhouse for Increased Biogas and Electricity Generation. *2nd African International Conference on Industrial Engineering and Operations Management*.
35. Kothari, R., Azam, R., Bharti, A., Gorla, K., Allen, T., Ashokkumar, V., Pathania, D., Singh, R. P., & Tyagi, V. (2024). Biobased treatment and resource recovery from slaughterhouse wastewater via reutilization and recycling for sustainable waste approach. *Journal of Water Process Engineering*, 58, 104712. doi: [10.1016/j.jwpe.2023.104712](https://doi.org/10.1016/j.jwpe.2023.104712)
36. Bhunia, S., Bhowmik, A., & Mukherjee, J. (2022). Waste management of rural slaughterhouses in developing countries. In *Elsevier eBooks* (pp. 425–449). doi: [10.1016/b978-0-323-85792-5.00019-8](https://doi.org/10.1016/b978-0-323-85792-5.00019-8)
37. Kulikova, M. A., Kolesnikova, T. A., Gribut, E. A., Okovitaya, K. O., Surzhko, O. A., & Zemchenko, G. N. (2020). Research on waste management technologies in meat clusters. *IOP Conference Series Earth and Environmental Science*, 421(2), 022064. doi: [10.1088/1755-1315/421/2/022064](https://doi.org/10.1088/1755-1315/421/2/022064)
38. Ali, A. F., & Gujiba, U. K. (2024). Household wastewater management in sub-Saharan Africa: a review. *Discover Water*, 4(1). doi: [10.1007/s43832-024-00060-6](https://doi.org/10.1007/s43832-024-00060-6)
39. Olawuni, P., Daramola, O., & Soumah, M. (2017). Environmental implications of abattoir waste generation and Management in developing countries: the case of Lagos State Abattoir in Agege, Nigeria. *Greener Journal of Social Sciences*, 7(2), 007–014. doi: [10.15580/gjss.2017.2.050715068](https://doi.org/10.15580/gjss.2017.2.050715068)
40. UNEP. (2023). Environmental Rule of Law: Tracking Progress and Charting Future Directions. Retrieved from <https://www.unep.org/resources/publication/environmental-rule-law-tracking-progress-and-charting-future-directions>
41. Forhad, H. M., Uddin, M. R., Chakrovorty, R. S., Ruhul, A. M., Faruk, H. M., Kamruzzaman, S., Sharmin, N., Jamal, A. S. I. M., Haque, M. M., & Morshed, A. M. (2024). IoT-based Real-Time Water Quality Monitoring System in Water Treatment Plants. *Heliyon*, 10(23), e40746. doi: [10.1016/j.heliyon.2024.e40746](https://doi.org/10.1016/j.heliyon.2024.e40746)
42. Bakare-Abidola, T., Olaoye, J., & Yekinni, O. S. (2025). Environmental assessment of heavy metal contamination and physicochemical properties in abattoir wastewater. *GSC Advanced Research and Reviews*, 22(3), 92–102. doi: [10.30574/gscarr.2025.22.3.0067](https://doi.org/10.30574/gscarr.2025.22.3.0067)