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COLLEGE OF VETERINARY MEDICINE AND AGRICULTURE

DEPARTMENT OF VETERINARY MICROBIOLOGY, PARASITOLOGY AND POULTRY HEALTH

MASTER OF SICIENCE PROGRAM IN ONE HEALTH

ASSESSING FOOD SAFETY MANAGEMENT SYSTEM: ONE HEALTH APPROACH TO IMPROVE WATER QUALITY AND MEAT HYGIENE IN ABATTOIR IN AND AROUND ADDIS ABABA ETHIOPIA

MSc THESIS

BY

SEBLE AWEKE TOLERA

JUNE, 2025

BISHOFTU, ETHIOPIA

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As members of the Examining Board of the final MSc open defense, we certify that we have read and evaluated the Thesis prepared by Seble Aweke Tolera, entitled '***Assessing Food Safety Management System: One Health Approach to improve Water Quality and Meat Hygiene in Abattoir in and around Addis Ababa Ethiopia'*** and recommended that it is accepted as fulfilling the thesis requirement for the degree of Masters of Science in One Health.

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STATEMENT OF THE AUTHOR

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ABBREVIATIONS

ACEWM	Africa Center of Excellence for Water Management
ARSO	African Regional Organization for Standardization
EPA	Environmental Protection Agency
APHA	American Public Health Association
APIQTC	Animal product and input quality testing centers
BPW	Buffered Peptone Water
CAC	Codex Alimentarius Commission
CAIFS	Codex Alimentarius International food standards
DO	Dissolved Oxygen
EAA	Ethiopian Agricultural Authority
ESA	Ethiopian Standards Agency
FAO	Food and Agriculture Organization
FBDs	Food Borne Diseases
FNP	Food and Nutrition Policy
FSMS	Food Safety Management System
GAIN	Global Alliance for Improved Nutrition
GAP	Good Agricultural Practices
GDP	Gross domestic product
GHP	Good Hygiene Practices
GMP	Good Manufacturing Practices
HACCP	Hazard Analysis Critical Control Points
ICP	Inductively Coupled Plasma
ISO	International Organization for Standardization
OES	Optical Emission Spectrometer
OH	One Health
OHHLEP	One Health High Level Expert Panel
SOP	Standard Operating Procedures
SSOP	Sanitation Standard Operating Procedure (SSOP)
STEC	Shiga toxin-producing *E. coli* serotype
TDS	Total Dissolved Solids
PPE	Personnel Protective Equipment
UNEP	United Nations Environment Programme
UVR	Ultraviolet radiation
WHO	World Health Organization
WTO	World Trade Organization

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ABSTRACT

Foodborne diseases pose a major global public health challenge, particularly in low-income countries like Ethiopia, where food safety in abattoirs is a serious concern. This study aimed to assess food safety management systems in six Central Ethiopian abattoirs using a cross-sectional design from October 2024 to April 2025. A total of 108 individuals were surveyed, and 120 samples were collected for microbial analysis focusing on water quality and meat hygiene within the One Health framework. Data were gathered through questionnaires, observations, and microbial testing. Microbial loads (Aerobic plate count, *S. aureus*, and *E. coli*) were quantified and identified using bioMérieux TEMPO®, and OmniLog ID System, respectively. Questionnaire observational survey findings revealed significant weaknesses in the implementation of Food Safety Management Systems (FSMS) while respondents generally reported adherence to hygienic protocols and the use of personal protective clothing. However, direct observation indicated a lack of consistent and proper application. Only about a one-third of facilities conducted internal hygiene audits. For water hygiene, while many facilities performed regular testing, less than half maintained proper records, indicating significant gaps in documentation and monitoring. Furthermore, observations highlighted inadequate infrastructure including poor ventilation, insufficient designated processing areas, and ineffective waste management systems. Additional study with sample analysis from these facilities showed an overall highest mean APC, *S. aureus* and *E.coli* in sampled water, equipment and in both equipment and hands, respectively. Further microbial analysis revealed significant differences in microbial loads across abattoirs and sample types ($p<0.05$), likely due to varying hygiene practices. The identification of pathogens such as *E. coli* O157:H7, Salmonella and *S. aureus* in this study across different abattoirs and samples including water implies a serious public health concern that needs rigorous interventions. In addition to poor microbial quality, the water used for cleaning in the abattoirs showed high concentration of some of the harmful toxic metals (Cd, Pb, and Mn) and salinity which can further compromise food safety thereby requiring urgent attention. The study highlights critical gaps in food safety management and hygiene practices, evidenced by high microbial loads and heavy metal concentrations, which calls for interventions measures through implementation of proper hygienic protocols and comprehensive personnel training to safeguard the public health.

Keywords: Abattoirs, Hygienic practices, Carcass, Microbial quality, Harmful toxic metals, Ethiopia

1. INTRODUCTION

1.1. Background

Globally in each year, the leading percentage of population is exposed to food borne diseases, with approximation of around one in ten people falling ill after consuming contaminated food. This causes complications, hospitalizations, and even loss of life to hundreds of millions of cases annually. Vulnerable groups, such as children, the aged, and those who have weak immune systems, are predominantly at risk. The main causes of foodborne diseases include bacteria, viruses, and parasites, which can inter at various points of the food supply chain from production up to consumption. The influence on the economy is also important as food borne diseases have a substantial burden on the health care system and lead to loss of productivity and strengthened food safety regulation (WHO, 2021).

Many diseases and other health conditions like communicable and non-communicable diseases, impaired growth and development, micronutrient deficiencies and mental illness are linked to unsafe foods and fortunately, the majority of these diseases can be prevented. Ensuring food safety is shared responsibilities, providing safe food globally in a sustainable manner for the present and future generation that needs multi sectorial coordination amongst different communities, businesses, national and local scale (FAO, 2022).

Safe food is a known concept globally vital to ensuring food security and health diets. Ensuring food safety is essential in advancing health, livelihoods, trade, economic growth, and general prosperity (Framework, 2023). The effects of the food system extend beyond human health to include the environment and animal health. There is currently a pressing need to create multi-stakeholder plans that can eradicate poverty and preserve the planets and people's prosperity and health. It is crucial to produce multidisciplinary knowledge on the promotion of human well-being in relation to numerous interconnected factors, including diet and nutrition, the environment, economic, social, and legal aspects, in order to better understand the complex relationships between food, well-being, and the environment (Martini *et al.*, 2021).

Animal Source Foods (ASFs) are important sources of protein and other vital micronutrients such as vitamins and minerals. However, the food needs to be safe and free from contamination that affects human health. Food safety is mainly secured by an integrated, multidisciplinary approach that considers the whole food chain particularly the contamination of food may occur at any stage in the process from food production to consumption ("farm to fork"). A food safety system should take into account the complexity of food production and the globalization of the food supply and should be risk-based. Hazards and potential risks should be considered at each stage of the food chain, i.e. primary production, transport, processing, storage, and distribution, to ensure that appropriate risk mitigation measures are in place (WOAH, 2023).

Food safety is particularly concerned with the unintentional contamination of food products during the processing or storage of animal-derived foods. The primary categories of food safety hazards include biological, chemical, and physical contaminants (Ahmed and Al-Mahmood, 2023). In the meat processing sector, food safety is of utmost importance, especially in abattoirs, where the primary sources of microorganisms include the animal's skin, surfaces that come into contact with meat (such as tables, axes , hooks, scales, and knives), as well as the clothing and hands of the personnel involved in meat processing. Ensuring the safety of meat products is critical to safeguarding consumers from foodborne diseases and promoting public health (Chutia *et al*., 2019).

The concepts of food safety and food security are interconnected and significantly influence the quality of human life. Numerous external factors affect both domains. Food safety covers a wide range of concerns related to the handling, preparation, and storage of food. Water is an inherent component of food production. An in-depth understanding is required to know the impact of these factors on food safety (Bhagwat, 2019). The key dimensions of water that are of importance to water plays a crucial role in transporting both microbiological contaminants (such as pathogens from human and animal sources) and chemical contaminants (like harmful toxic metals from the environment) into the food chain. Poor water quality can lead to different types of contaminants affecting food safety at every stage known that it's essential and varied uses all the way through food chain (FAO, 2024).

Freshwater resources are weakening and people are increasingly relying on unprotected and unsafe water sources in many developing countries, leading to a significant number of deaths due to waterborne diseases. Although Ethiopia is home to many of Sub-Saharan Africa's major rivers, providing an average of 1,575 m^3 of water resources per capita per year, most of the drinking water comes from groundwater. This is because the large water volumes are not available consistently in terms of time and location (Siraj *et al*., 2016).

Ethiopia's capital and commercial center, Addis Ababa, faces a persistent water supply crisis, despite the country's enormous water potential, the municipal water system is inadequate to meet the city's domestic and industrial needs. Consequently groundwater which is mainly unregulated is used by a lot of industries including slaughterhouses. This raises questions regarding the possibility of contamination as well as the sustainability of water sources. Some slaughterhouses do use municipal water which is usually regarded as microbiologically safe but because of the city's water shortages it is getting harder to find and more expensive (Alegbeleye *et al*., 2024). Particularly to these challenges, it is fundamental to assess water quality and current practices in abattoirs to direct interventions aimed at improving food safety and public health outcomes. In order to reduce the risk of contamination during production and processing food safety principles like Hazard Analysis and Critical Control Point (HACCP), Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and Good Agricultural Practices (GAP) are essential. To guarantee the safety of the food they produce, food producers must follow certain regulatory procedures (Gadekar *et al*., 2021).

The red meat industry also adds considerably to a nation's economic growth. However, there is widespread concern around the world about the public health issues brought on by significant food safety incidents in the red meat sector. Numerous of these incidents are linked to foodborne illness emergencies, which have a big effect on food businesses, individual consumers and society at large (Warmate and Onarinde, 2023).

1.2. Statement of the Problem

Each year, an estimated 600 million people are sickened, and 420,000 die from foodborne disease (FBD), resulting in the loss of more the 33 million healthy life years (Havelaar et al., 2015). Low- and middle-income countries bear a disproportionate amount of this burden at a significant cost to human health, trade, and development (Grace, 2015).

WHO report on foodborne illnesses showed a significant global health challenge with over 600 million cases occurring annually and resulting in approximately 420,000 deaths. These number can be extrapolated into one in ten individuals which may fall ill after consuming contaminated food. Furthermore, children under five years old are disproportionately affected with 40% of the foodborne disease burden, which translates to around 125,000 deaths each year (Asif *et al.*, 2024). In this regard, Quality and Standard Authority of Ethiopia is the national standard body in the country under the Ministry of Science and Technology mandated to ensure food safety through certification, inspection and testing (Erkyihun, 2010).

In Ethiopia, food safety represents a significant public health issue, primarily due to unhygienic food handling practices and a high prevalence of food adulteration, which adversely affects the lives of consumers through foodborne illnesses. Thus, food safety challenges due to poor infrastructure, absence of clean water and sanitation, weak regulation and non-compliance with regulation cause risk to public health and economic growth (GAIN, 2022). In Ethiopia, the prevalent foodborne pathogens identified which include Salmonella, *Listeria monocytogenes*, *Escherichia coli*, Campylobacter species, and Shigella (Belina *et al*., 2021). Previous report in Ethiopia showed the presence of a high occurrence of food borne disease (Abebe *et al*., 2020; Belina *et al*., 2021; Mekonnen *et al*., 2021; Asfaw *et al.*, 2022). Whereas the current studies not only detects microbial and chemical contaminants but also evaluates hygiene practices and the effectiveness of FSMS using a One Health framework. This approach considers the interconnected health of humans, animals, and the environment.

The meat industries in Ethiopia especially in and around Addis Ababa with high meat production to supply meat for residents, the abattoirs are operating in substandard conditions facing significant challenges related to food safety and hygiene, which is characterized, by inadequate hygiene practice, poor water quality, and food safety management system effectiveness. Many abattoirs operation lack food safety management system in spite of existing regulation guidelines leading to unsafe meat products and increased public health risk. However, few studies (Kebede *et al*., 2016; Bersisa *et al*., 2019; Gutema, 2021) have targeted specific pathogens from carcass swabs, and there has been limited research on food safety, particularly with an integrated one-health approach. Therefore, it is essential to prioritize the search for solutions to enhance health, as well as the quality and improve availability of safe meat products for the public.

General objective

To evaluate water quality, hygienic practices, and food safety management systems in abattoirs in Central Ethiopia, with the aim of identifying best practices and informing strategic improvements in the meat industry.

Specific objectives

The specific objectives of this study were: to assess the microbiological and physicochemical quality of water used in abattoirs in Central Ethiopia; to evaluate hygienic practices during slaughtering, meat handling, and sanitation in selected abattoirs; to examine the implementation and effectiveness of food safety management systems, such as Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practices (GMP), in abattoir operations; and to assess current food safety practices within the meat processing chain, identify key gaps and strengths, and recommend evidence-based strategies for improving overall food safety management.

2. LITERATURE REVIEW

2.1. Food Safety Management Systems

The requirement of any organization in the food chain regarding Food Safety Management Systems which is ISO 22000 is widely recognized. It is considered an important part of international guidelines for developing a robust food safety management system (FSMS). This requirement involves the essential actions an organization must take to prove its capability to manage food safety hazards and guarantee the safety of food products for consumers. It enables organizations to consistently provide food products and services across the entire supply chain (ISO, 2018).

The food system comprises the interconnected steps required to transport food from farms to consumers. These steps include production, processing, distribution, consumption, and disposal; all depend on both human and natural resources. Furthermore, food must go through a number of steps including production processing and distribution before it can be sold and consumed (Panda 2022). A thorough FSMS incorporates globally accepted frameworks such as Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP).The standards of food safety deliver guidance on identifying and controlling potential hazards, taking preventive measures, and maintaining high standards of hygiene and quality (Gadekar *et al*., 2021).

Globally, society is challenged with feeding, housing, and ensuring the well-being of a growing population while also safeguarding the environment and natural resources for future generations. To overcome these challenges necessities a sustainable food production and assurance to environmental stewardship this can be succeeded through the One Health principle. The interdependence of environmental animal and human health is emphasized by this method. In order to address these issues the one health approach unites interdisciplinary teams to create a network that tackles food safety, sustainable production and environmental stewardship (Garcia *et al*., 2020).

2.1.1. Importance of effective food safety management systems

Food Safety Management Systems (FSMSs) are created to assist manufacturers and their supply chains in safeguarding consumers while upholding robust business reputations. However, implementing FSMSs can be challenging, and maintaining their ongoing effectiveness poses further difficulties (Maiberger and Sunmola, 2022).

ISO 22000 plays a significant role for both consumers and companies as it helps organizations to enhance their whole performance by following structure approach. At every step of the food chain from farm to fork ISO 22000 helps to identify, prevent and control food safety hazards. Despite its size or structure, this standard is relevant to all facilities involved in food production, supplies and food contact materials, as well as in retail and other related areas (ISO, 2018).

Food is a basic human necessity and similarly safe food is another important food factor which is crucial for maintaining the safety of public health. This is due to the fact that the incidence of foodborne disease outbreaks is increasing and has become a global concern. For example, meat which is rich in essential nutrients can provide an ideal environment for microbial growth. Without proper precautions, post-slaughter processing can be a significant source of contamination (Gadekar *et al.*, 2021). Food of animal origins including dairy, eggs, fish, and meat are vital for providing high-quality nutrients. However, the production and consumption of these foods also pose potential food safety risks. It is important to strengthen food control systems which need to be guided by assessment of disease burden from food of animal origins. With this into effect the objectives of global nutrition can be met (Li *et al*., 2019).

2.1.2. Regulatory Frameworks and Standards for Abattoir Operations

Ensuring the quality and safety of domestically produced, exported, and imported food and food products is a crucial component of food quality and safety measures. It is based on the premise that maintaining the quality of these foods is vital to protect public health, meet consumer expectations, boost foreign earnings, and sustain the confidence of food trading partners.

Consequently, governments take measures to guarantee the quality and safety of food and food products across domestic production, imports, and exports (Temesgen and Abdisa, 2015).

The Codex Alimentarius also known as “the Codex” is a compilation of internationally recognized standards, guidelines, and codes of practice for food safety and quality, established jointly in 1963 by FAO and the World Health Organization with the general aim of protecting consumer health (thereby maintaining food trade in a fair manner, promoting globally harmonized international food standards) (FAO and WHO, 2019a).

FAO and WHO strategic directions on food safety have acknowledged the crucial role of food control systems in achieving the UN Sustainable Development Goals. They also recognized the significance of agri-food systems in addressing major global drivers, such as environmental changes and digital advancements, in response to emerging hazards in the food chain. Additionally, they emphasized approaches to mitigate challenges, including food system transformation and the promotion of the One Health approach (Anonymous, 2024).

Abattoirs need to take a good understanding of the regulatory requirements applicable to their operation and this includes matters such as animal welfare, food safety, sanitation, waste management, labeling and worker safety. It is very important for professionals working in abattoirs to be informed of laws and standards that need to be applied in their establishment (in turn, thus they can ensure compliance from the inception work flow design of its food safety orientation) (Anonymous, 2023a). Food safety management measures such as Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and Standard Operating Procedures (SOPs) during slaughtering and processing of meat to minimize contamination risks and ensure quality meat production. Moreover, the Sanitation Standard Operating Procedure (SSOP) defines the steps to be followed for thorough cleaning and sanitization of both meat contact surfaces and non-product surfaces (Ahmed and Al-Mahmood, 2023).

2.2. Water Quality in Abattoir Operations

2.2.1. Water quality for Meat Quality and Safety

Water safety and availability, which should be guaranteed and accessible at all times, will be of critical importance to public health, whether water is being consumed for drinking, domestic use, food production or recreational uses, and water supply and sanitation improvements in addition to improved management of water resources can further promote economic growth and consequently poverty alleviation (WHO, 2023).

Water is used in the entire food chain from initial sourcing, storage, treatment and distribution. It is used for irrigation of food crops and forage for animals, primary production, food processing and consumption of the final product. Also used as an ingredient it is in direct and indirect contact with food, food packaging and hygiene and sanitation in food processing. Water as such must be safe and of good quality, since it can carry diseases, contamination or undesirable sensory characteristics (Codex Alimentarius, 2023).

Water is a diverse resource accounting for approximately 75% of the earth's surface. It has special physical, chemical, and biological characteristics required for plant and animal living things (Espinoza, 2017). The water used in abattoirs for such activities as meat processing, cleaning, and feeding animals have to meet international potable water standards and be free from toxicity levels of chemicals, physical contaminants, or microorganisms that could contaminate the water (Aiyedun *et al*., 2022).

Water quality has an essential role in all food production processes and so it is a fundamental aspect. In production of food the source of water and the method for its use are important factors that determine the quality of water. Pollution of water may occur at all stages of the food production process and in several ways. Microorganisms that are pathogenic pose a significant challenge to food safety and also to both human and animal health and because of contaminated fresh water that are pathogenic most of the diseases transmitted. In food products when water is used, it must not have unpleasant taste, odor, color, and impurities including pathogenic organisms which can affect consumer health and negatively affect the quality of product. Its quality must be consistent with safe drinking water standards (Bhagwat, 2019).

2.2.2. Water Quality Standards

When assessing the requirements for water quality use along the food chain, it is significant to take into account the anticipated use of the water, any potential risks, and whether any additional steps are being taken to reduce the risk of contamination. Drinking water safety Improvements in water quality should be made step by step according to WHO's approach, because the accessibility and quality of water vary by nation, location, context, setting, and food institution. Although the quality of water varies depending on the condition, it may be suitable for some uses. The evaluation of the source water, possible risks associated with this water source, treatment alternatives and their effectiveness, various barrier procedures, and the final usage of the food product (such as if consumed raw) must all be taken into account when determining if water is suitable for its intended use (FAO and WHO, 2019b).

Characteristics of water are assessed based on physical, chemical and microbiological content. The color, odor, taste, temperature, and turbidity, when water physically evaluated indicated pollutants or organic matter presence. Parameters like pH, dissolved oxygen (DO), total dissolved solids (TDS), nutrients (e.g., nitrates and phosphates), hardness, and conductivity are fundamental in determining chemically water is fit for a given use. The microbial content, existence of algae, and overall biodiversity are key pointers of water safety and environmental health from a biological perception (Arora *et al*., 2017). Furthermore on earth's crust harmful toxic metals are naturally occurring elements existing in but excessive amounts of harmful toxic metals can pose significant risks that put concern progressively on a global scale. With the issues related to health implications harmful toxic metals like Manganese (Mn), lead (Pb), cobalt (Co), copper (Cu), and nickel (Ni) have brought in significant attention (Rahman *et al*., 2019).

2.2.3. Water borne pathogens in abattoir

Global problems with significant morbidity and mortality rates are the presence of pathogenic illnesses that are transmitted through food and water sources. Therefore, the monitoring of food- and water-borne pathogens is a critical aspect of control (Reddy *et al*., 2022). Polluted water is used in case of local production for different purposes like production of food , processing and consumption, which have huge impact on human health but still no concrete scientific evidence is present. The impact of water quality on the food system depends on the food produced, the type of contaminant and techniques of food preparation (Linderhof *et al*., 2021).

In food production and processing water quality affects both food quality and security. To have healthy and hygienic food the water used in food processing must have a good quality. It is very vital that examination of water with strict quality control criteria must be present at every step of food processing, packaging, and storage (WHO, 2017).

Waterborne pathogens commonly associated with abattoirs are salmonella, *E. coli*, Campylobacter, and listeria. These pathogens can potentially contaminate water via contamination with sources such as untreated effluents thereby impacting public health risks to the nearby personnel (Eze and Phil-Eze, 2020). However, efforts can be made to mitigate those risks such as abattoir wastewater treatment before releasing to the environment. Additionally, the implementation of strict hygienic protocols in the abattoir facility can safeguard the potential impacts of those pathogens on public health (Svanstrom, 2014).

2.2.4. Strategies for improving water quality

To make water safe and used for intended purpose in municipal disinfection of water is done to remove biological contaminants. There are several types of water disinfection methods used in the water supply: ultraviolet radiation (UVR), chlorination, ozone, chloramination (CM) and chlorine dioxide using eight evaluation criteria (Gelete *et al*., 2020). The choice of the most suitable water treatment technique depends on the water source and the intended application of the water additionally; it depends on the design aspects of storage and distribution in a food manufacturing facility. To effectively control microbial contamination hygienic design of the water distribution and storage systems is used (Bhagwat, 2019).

The meat processing sector is among the largest freshwater users within the agricultural and livestock industries globally. Facilities of meat processing produce significant quantities of wastewater from operations of both slaughtering and cleaning processes. Thus, wastewater because of its high content of organic matter and nutrients needs considerable treatment before it can be released safely into the environment. As a result, addressing slaughterhouse wastewater treatment and final disposal is essential for public health and the ecosystem (Bustillo-Lecompte and Mehrvar, 2017).

Abattoir wastewater uncontrolled release poses a major global concern due to its negative effects on public and environmental health. The lack of wastewater treatment facilities and proper disposal rules leads to various ecological concerns in many developing countries. Various researches have shown that this wastewater can be a nutrient source for harmful microorganisms. Therefore, abattoir wastewater treatment is essential for successfully minimizing the environmental pollution it can cause (Adamu and Dahiru, 2020).

2.3. Hygienic Practices in Abattoirs

Slaughterhouses are designed to produce wholesome and safe meat maintenance of hygiene standard, facilities, and compliance of policies which is mandatory and failing to comply with those factors result in high risk to public health and environment (Ahsan *et al*., 2020). Regular training and certification programs for abattoir staff are important to keep and increase hygiene and food safety practice. These include proper handling of carcasses, identification and prevention of foodborne hazards, and compliance with regulatory requirements. Training ensures that all staff members are knowledgeable and equipped to implement effective food safety measures (Anonymous, 2023b).

According to FAO and WHO (2023a), food hygiene was defined as “All conditions and measures necessary to ensure the safety and suitability of food at all stages of the food chain. Food hygiene systems are prerequisite program, supplemented with control measures at critical control points

(CCPs), as appropriate, that, when taken as a whole, ensure that food is safe and suitable for its intended use".

2.4. Public health implications of abattoir operations

Abattoirs are an establishment where livestock are slaughtered and have a vital role in the food production chain. There are different kinds of abattoir that vary in terms of infrastructure, hygiene practices, personal protective equipment (PPE) standards, and adherence with guidelines. Animals and animal products interact within these facilities, workers exposed an increased risk to zoonotic pathogens, also Backyard abattoirs and slaughter slabs pose the highest risk for pathogen transmission, largely due to inadequate hygiene practices and poor infrastructure. These conditions can lead to environmental contamination and significantly contribute to disease outbreaks in surrounding communities (Rodarte *et al*., 2023).

Ensuring meat safety with inspection serving as an important mechanism for controlling animal diseases and protecting public health is the main aim of slaughterhouses. Additionally, slaughterhouses can function as surveillance centers for livestock diseases (Garcia-Diez *et al*., 2023). Food safety concerns have not been considered a development priority. Assessing FBD in developing countries is not easy because many infectious diseases have no definitive diagnosis, that is, one which identifies the pathogen responsible. However even if a diagnosis is known , it may be difficult to know if the source was food, water, other people, animals or the environment. Moreover, there is a perception that FBD is a minor inconvenience and that it is largely unavoidable (Gace, 2017). Bacterial pathogens are a major cause of food safety issues, both in terms of their frequency and the number of people affected. Common bacterial pathogens found in meat and poultry products include Campylobacter species, Salmonella species, *Escherichia coli* O157:H7, *Staphylococcus aureus*, and *Listeria monocytogenes* (Zelalem *et al*., 2019).

2.5. One health approach to food safety management

2.5.1. Role of One Health Approach in Food Safety

One Health represents a rapidly growing range of interaction of many disciplines, including food safety, public health, economics, ecosystem health, social science, and animal health, for addressing complex health problems (Xie *et al*., 2017). The food safety of livestock is a vital issue between animals and humans due to their complex interactions. Pathogens have the potential to spread at every stage of the animal food handling process, including breeding, processing, packaging, storage, transportation, marketing, and consumption. In addition, In food animal production systems the increasing application of antibiotics in food animal production systems can fight food-borne zoonotic pathogens and promote animal growth and productivity, but may result in the emergence of antibiotic-resistant bacteria that are transmissible to humans through the food chain. In public health antibiotic resistance has a negative consequence which causes resistance to treatment and increased severity of disease (Kaur 2024).

A key element of the One Health approach to increasing food safety is recognizing that foodborne pathogens can be transmitted through various routes from animals and the environments involved in food production and processing. Notable foodborne pathogens like Salmonella and Campylobacter originate in animals, develop in farming settings, and eventually enter the food supply chain. By applying the One Health approach, we can better understand the multiple pathways of pathogen transmission, and identify, and reduce risks at every stage of the food production process (King *et al*., 2008).

In East Africa, a region with many endemic and emerging zoonoses, and in countries such as Ethiopia in particular, One Health (OH) approaches are increasingly seen as effective ways, to mitigate the risk of zoonosis at the interface between human, animal and the environment. The OH approach promotes interdisciplinary cooperation and collaboration between researchers and practitioners from the disciplines of human, animal and environmental health. Moreover, it advocates for the establishment of a public health sector model which recognizes the imperative to holistically address diseases that occur in the human, animal and environmental health arena (Nyokabi *et al*., 2023).

2.5.2. Principles of One Health

Concept known for over a century: Human and animal health's are interdependent and linked to the health of the ecosystems in which they coexist is the One Health approach which was introduced in the 1990s. It is a collaborative effort involving a multidisciplinary approach of several disciplines at local, national, and global levels, aiming to achieve optimal health for people, animals, and the environment. The One Health approach is particularly relevant in areas of activity in which include food safety, the control of zoonosis, and the fight against antibiotic resistance (WHO, 2017).

One Health is a concept developed by the One Health High Level Expert Panel (OHHLEP) as an integrated framework which intends to sustainably optimize and balance the health of humans, animals and the ecosystem. It understands and integrates the health of human beings, domestic and wild animals, plants and the environment (including ecosystems). Such an approach brings together many sectors, disciplines, and communities from different societal levels to collaborate in promoting well-being and mitigating the health and ecosystem issues alongside the growing demand for food, clean water, energy, unpolluted air, climate action, and sustainable development (Adisasmito *et al*., 2022).

The public health and environmental dimensions within the animal health system are significant because the capacity of Veterinary Services to detect a disease is important for the early warning of the possible emerging disease problems for animals and/or humans and, therefore, is highly important for the control and prevention and early diagnosis of zoonotic spillovers. In trying to achieve these benefits, rapid joint risk evaluation and timely information sharing with relevant parties is crucial (WOAH, 2023).

2.5.3. Interdisciplinary Collaboration in One Health

A coordinated and organized approach that recognizes the interdependence of human, animal and environmental health is to refer to the perspective of a "One Health" paradigm by encouraging stakeholders to solve health issues. There is a compelling argument made for a collaborative, multidisciplinary approach to health challenges. As a means to engage stakeholders; One Health looks to establish and promote communication and coordination between physicians, veterinarians, and ecologists, and others, to facilitate collaborative and multi-faceted approaches to disease prevention, control, and management (Cai *et al*., 2024).

In East Africa, a region with endemic and emerging zoonosis, and specially countries like Ethiopia in particular, "One Health" (OH) approaches can be seen as significant means by which individuals can help mitigate the risks and effects of zoonosis between humans, animals, and the environment. One Health approaches emphasize the importance of interdisciplinary cooperation and collaboration between researchers and practitioners in the human, animal, and environmental health community. As well, One Health proposes the need to develop a public health model to address and promote health issues impacting humans, animals, and the environment in an integrative manner (Nyokabi *et al*., 2023).

Although the One Health model is based on "One Medicine", Schwabe (1984), One Medicine accepts the essential similarities in disease processes irrespective of the host species. A One Health approach makes sense because most Ethiopians are at risk for zoonotic diseases. Ethiopians engage daily with zoonotic disease risk based on their fundamental interaction with livestock; eating animal products derived from animals such as meat, raw milk, blood, and, a lack of medical and/or facility access, as well as resorting to live in unsanitary environmental conditions with animals (Griffith, 2020; Cavalerie, 2021; Erkyihun, 2022).

Collaboration of human, animal, and environmental health is needed for the Success of public health interventions. Additionally, professionals in human health (doctors, nurses, public health practitioners, epidemiologists**),** animal health (Veterinarians, paraprofessionals, agricultural workers), environment (Ecologists, wildlife experts), and other areas of expertise must be communicate, collaborate on, and coordinate. Other relevant actors also included in the One Health approach like law enforcement, policymakers, agriculture, communities, and every person, organization, or sector can address issues at the animal-human-environment interface alone (CDC, 2024).

2.6. Abattoir operations and food safety management system in Ethiopia

2.6.1. Livestock Production and Slaughterhouse Infrastructure in Ethiopia

Agricultural development in Ethiopia is considered an important issue addressed mainly by the government to stimulate a general increase in economic activity, eliminate poverty and ensure food security (Shapiro *et al*., 2017). Livestock production is significant to agricultural farming systems and supplies significantly to the country's economy. Livestock population in Ethiopia is estimated at about 58.43 million cattle, 6.91 million small ruminants, 8.15 million camels, 9.98 million equines and 1.38 million chickens. Meat animals are animals such as beef cattle, small ruminants and camels raised solely for their meat, whether for domestic consumption or sale CSA (2021).

Population growth in animals and humans will increase risk of spread of zoonotic diseases including infectious, emerging and reemerging diseases. Additionally Increasing interaction with wildlife will further exacerbate this risk. Even in the best-case scenario, emerging infectious disease outbreaks have brutal consequences within and outside the livestock sector. Other than animal loss, production loss and human infections, outbreaks of emerging and re-emerging diseases can result in restriction of people’s movements, closure of businesses and public offices, trade bans, decrease in tourism, social unrest, and political instability (FAO, 2019).

In the modern urban community a slaughterhouse is a significant facility that provides safe and hygienic conditions for processing of animals, allowing the production of meat products safe for intended use (Coelho *et al*., 2022). In addition to ensuring the safety and hygiene of meat production, slaughterhouses also have an important role in regulating and inspecting meat quality by protecting consumers from potential health risks and ensuring that only high-quality meat reaches the market (WOAH, 2023).

A standard slaughterhouse should have the following elements: stall, slaughtering room, slaughtering slab, intestinal, hind, retained meat, offal and condemned meat section, water supply, and cold storage. Other elements include veterinary inspection and health section, veterinary office, laboratories, and waste disposal facilities (Gali *et al*., 2020). Nevertheless, in Ethiopia livestock production and meat processing systems are generally survival based with reduced productivity. In addition, low animal productivity and lack of market-oriented production systems are described as the main constraints of the meat processing industry in the country. The demand for live animals and meat processing creates various opportunities, including domestic consumption, official exports, and a strong need for livestock from export slaughterhouses (Tesema and Tolesa, 2020).

2.6.2. Operation and Facilities of the Abattoir in Ethiopia

According to Alonge (1991), a slaughterhouse is a facility approved and registered by a governing body that follows the hygienic slaughtering and inspection of animals, processing, storage, and effective preservation of meat products intended for human consumption. In addition to ensuring the safety and hygiene of meat production, slaughterhouses also have an important role in regulating and inspecting meat quality by protecting consumers from potential health risks and ensuring that only high-quality meat reaches the market (WOAH, 2023).

Foodborne disease incidents in a large proportion are caused by foods that are mishandled at home or in a manner not in accordance with accepted standards in food service establishments, or at markets. Food safety is a primary public health concern, and achieving a safe and sustainable food supply has continue to be major challenges for national food safety officials. Global patterns of food production changing, international trade, technology, public expectations for health protection and many other factors have created an increasingly demanding environment in which food safety systems operate (Idiris, 2021).

In Ethiopia, there are more than 300 local abattoirs which produce meat for local consumption at different locations with different capacity and facilities but with no standards (Eshet, 2018). On the other hand, meat and live animals are exported to the Middle East and some African countries. Chilled/frozen beef, goat meat, mutton, chilled beef, chilled camel meat and red mullet are mainly exported to the United Arab Emirates (UAE), Saudi Arabia, Angola, Egypt, Bahrain, Turkey and Kuwait. This exported meat is sold via formal channels, under the country's regulations. Export slaughterhouses must meet stricter hygiene and safety standards to fulfil international requirements and have facilities usually with larger infrastructure and modern equipment that ensure the safety and quality of the food they produce. Thus the establishments must adhere to rigorous inspection procedures, such as HACCP and ISO certification, and are mainly focused on foreign markets, especially in the Middle East (Eshetu and Abraham, 2016).

According to various criteria slaughterhouses can be classified such as ownership, size of operation, and services provided. There are different types of slaughterhouses in Ethiopia including municipal, private, and export. Each category of slaughterhouse has specific operational procedures and also challenges which are shaped by local laws, market needs, and resource availability. These slaughterhouses vary in size and complexity, influenced by location and local regulations. Facilities such as stalls, slaughterhouses, cold rooms, and others are mandatory for smooth operation. In developing countries, public slaughterhouses often suffer from poor infrastructure, inadequate sanitation, water shortages and inadequate waste management facilities (Ovuru *et al.,* 2024).

Meat is a perishable food, poor personal hygiene of meat handlers can result in the spread of germs through their hands, clothing, wounds and hair (Wambui *et al.*, 2017). Failure in keeping hygienic practices, such as hand washing, use of protective clothing, cleaning of equipment and utensils, have higher risk to contaminate meat by pathogens and cause illness in consumers (Siluma *et al*., 2023).

According to Bersisa (2019) and Gutema (2021), poor establishment and lack of sanitary practices in slaughterhouses or abattoirs result in microbial contamination of meat. To address these issues improving operational facilities, training and implementation of quality control systems is mandatory. Additionally, educational intervention like training is needed for slaughterhouse workers to improve meat safety (Zelalem *et al*., 2021).

Food safety and quality are generally the fundamental needs of consumers. In addition, transparency, honest and direct forward food information, based on science, is important to build consumer trust and advance food safety. The main role of a slaughterhouse is to ensure the safety of meat relative to animal pathology and diseases. However, it can also serve as a tool to monitor other impacts that affect not only animal health, but also food safety and public health (Garcia-Diez, 2023).

2.6.3. Food borne disease hazard in Ethiopia

Each year, foodborne disease (FBD) a health burden affects millions, creating the same magnitude as malaria, tuberculosis or HIV. In a recent World Bank assessment, treatment costs for these diseases were $3.5 billion and productivity losses in Africa were estimated to be $20 billion due to contaminated food in 2016. In Ethiopia there are many food safety challenges related to poor infrastructure, lack of access to basic food safety needs (clean water and a sanitary environment), and no incentives for producers to enhance food safety (Gazu *et al*., 2023).In low-income countries mainly Foodborne pathogens (FBPs) are transmitted via the consumption of contaminated food or drinking water and cause noticeable public health risk (Gobena *et al*., 2023).

Meat has been found to be a prime vehicle for the dissemination of foodborne pathogens to humans worldwide. Microbial meat contaminants can cause food-borne diseases in humans (Rani *et al*., 2023). In Ethiopia, animals are commonly slaughtered, dressed and carcasses are distributed to consumers under unhygienic conditions that cause microbiological contamination and poor quality meat. This is due to the prevailing poor food handling and sanitation practices, inadequate food safety laws, weak regulatory systems, lack of financial resources to invest in safer equipment, and lack of training for food handlers (Nigatu *et al*., 2017).

Common cause Diarrhea which accounts for about 22.2% of all diarrheal illnesses in children in Ethiopia are because of food borne bacterial pathogens. These pathogens are nontyphoidal Salmonella (NTS), Shigella, Campylobacter, and diarrheagenic *Escherichia coli* (especially enterotoxigenic *E. coli*, or ETEC) (Zelelie *et al*., 2019). Cross contamination because of Inappropriate handling of raw meat is the main source of Food-borne disease outbreaks in developing countries (Adesokan, 2014). This risk is especially prominent in Ethiopia, where traditionally raw or undercooked beef dishes, such as steak ("kurt") and beef tartare ("kitfo"), are commonly consumed (Seleshe *et al*., 2014).

2.6.4.. Environmental health implications of abattoir operations in Ethiopia

Operations in the abattoir produce substantial amounts of liquid waste and which can have significant consequences for the environment. Proper waste management is a priority in slaughterhouse operations due to the significant amount of organic waste produced. This waste can contaminate soil and water sources, residential areas without proper management, resulting in nutrient overload and the spread of harmful pathogens. Improper disposal practices can result in runoff and drainage that pollute groundwater and pose health risks to communities and surrounding ecosystems (Yunus, 2019).

Slaughterhouse waste consists of many contaminants such as animal excrement, blood, bones, fats, animal trimmings, rumen contents and urine from operations or areas such as rearing, evisceration or bleeding, carcass processing and offal processing. These slaughterhouse wastes can be classified into solid, liquid, and gaseous forms. Slaughterhouse waste can have a detrimental effect on the environment, public health, animal health, and the country's economy if not managed and controlled effectively (Bandaw and Herago, 2017). Insufficient knowledge, negative attitudes, and poor practices 14 often result in ineffective waste management, a problem that is more pronounced in developing countries such as Ethiopia (Tolera *et al.*, 2022).

Release of pollutants such as ammonia, volatile organic compounds, and particulate matter into the environment raise an additional issue of slaughterhouse operations which is air quality. With their ongoing activities, continuous entrance of these pollutants to the environment can degrade air quality, which can lead to respiratory problems for slaughterhouse workers and the surrounding residents. In addition, unpleasant odors produced during meat processing can negatively impact the quality of life of people living near the establishment. Furthermore, the continued operation of slaughterhouses in residential areas can pose significant environmental risks, exacerbating health problems for people with pre-existing conditions (Odekanle *et al.*, 2020). Safe disposal, handling, and processing methods such as landfilling, composting, processing, incineration, anaerobic digestion, and blood processing are also very important to absorb our economic benefits from slaughter waste/by-products instead of controlling public health risks and environmental pollution (Bandaw and Herago, 2017).

2.6.5. Meat production challenges in Ethiopia with Food Safety Perspective

Livestock value chains provide livelihoods for actors in the meat and dairy value chain in Ethiopia, from dairy farmers to other value chain actors such as traders of milk, slaughterhouse workers, public health officials, veterinarians, butchers, dairy cooperatives, artisan milk processors and carriers. However, because of poor food safety and quality the development of these animal value chains is limited, while consumers are also exposed to public health risks due to poor animal handling and the hygiene practices of personal in the food value chain of milk and meat (Nyokabi *et al.*, 2023).

Ethiopia's ability to meet the demands of its food system is complicated as a result of population growth, urbanization, and resource scarcity. Meat production is still low even if Ethiopia has a large livestock population, and contributes about 0.2% of total global meat production. This is due to low harvest levels, lack of compliance with international standards, and legal and illegal live animal exports. Per capita meat consumption in Ethiopia is 8 kg, which is the lowest compared to developing (77 kg) and developed (25 kg) countries because of too low per capita income, non-commercial breeding practices and high meat prices in the domestic market (Birhanu, 2019). During meat processing activities, meat can be contaminated with pathogens. To produce safe and wholesome meat, meat handlers must practice in accordance with food safety standards (Taylor *et al.*, 2022).

In developing countries such as Ethiopia, the public health challenges posed by foodborne microbes are significant. These problems arise from inadequate food hygiene and handling practices, insufficient food safety regulations, weak enforcement systems, limited financial resources for protective measures and lack of training of food handlers (Tessema *et al.,* 2014). In many developing countries meat hygiene and safety are generally less well managed where meat for human consumption is approved based on visual inspection that is without routine microbiological testing (Cook *et al*., 2017). Unintentional meat contamination during slaughter is potentially linked to processing methods so in order to ensure food safety Hazard Analysis Critical Control Point (HACCP) framework design is crucial. Therefore, application of Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and Standard Operating

Procedures (SOPs) during slaughtering and processing minimize contamination risks and increase meat quality (Ahmed and Al-Mahmood, 2023).

2.6.6. Existing Regulations and Enforcement Mechanism to Ensure Food Safety

Ethiopian Standards Agency (ESA) is the first national standards body established in 1970 representing the country in international standardization efforts, particularly in the area of food and beverages, while keeping Ethiopia's interests. ESA, as the country's sole standards body, is a member of several international organizations, including the International Organization for Standardization (ISO), the Codex Alimentarius Commission (CAC), the African Regional Standards Organization (ARSO), and the World Trade Organization (WTO) (Abebe and Kassem, 2018).

The Federal Government of Ethiopia developed a Food and Nutrition Policy (FNP) in 2018, which recognizes food security and nutrition as a core responsibility of the government. The FNP laid down seven objectives focused at improving food safety and quality throughout the value chain. It also aims to create a policy framework to support food safety-related strategies, laws**,** and regulations across the food system. Even if FNP does not focus solely on food safety, it helps to strengthen the legal environment surrounding food safety in the country (GAIN, 2022).

In Ethiopia, food safety authority are distributed across different ministries like Ministry of Health, the Ministry of Agriculture, the Ethiopian Quality and Standards Authority, the Environmental Protection Authority, the Ministry of Industry, the Ministry of Trade, various federal government agencies and regional research institutes, the Ministry of Education, as well as food producers, distributors and hotels (Kalkidan *et al*., 2017). However, food safety responsibility for regulations, compliance, and inspection in Ethiopia is fragmented and disjointed across different ministries and executive governing bodies. Currently, no united coordination mechanism exists to make clear identification of overlaps or gaps in food safety regulations. The fragmentation of regulatory authorities was also seen in compliance and inspection activities. A lack of training for government personnel in food safety best practices (e.g., Good Agricultural Practices, Good Hygienic Practices, and Hazard Analysis Critical Control Point best practices) has led to reduction in managerial efficiencies and low levels of food safety expertise in Ethiopia's regulatory authorities (GAIN, 2022).

The European Union (EU) General Food Law in contrast to Ethiopia's food safety system provides an overall legal framework for ensuring food safety and public health protection across the entire EU member countries. It provides the general principles and regulatory requirements of food law such as the basis of risk analysis, the precautionary principle, and the duties of food business operators. Traceability is one of the fundamental elements of the law. Food and feed are traceable all the way from production through processing to distribution. The law also established the European Food Safety Authority (EFSA), an independent body providing scientific opinion on food-related hazards. Transparency and consumer protection are enhanced by the establishment that decisions made in regard to food safety should be science-based and made public. This legislation provides for the free movement of safe food throughout the EU with stringent human, animal, and environmental health requirements.(Pettoello-Mantovani *et al* ., 2022).

2.7. Critical Food Safety areas in Food Processing Plants

2.7.1. Hygiene and sanitation practices

In food processing plants, including slaughterhouses, hygiene practices are one of the important activities planned. To achieve this must apply sanitary measures and technologies, train and educate workers, and create awareness on the importance of hygiene practices in meat processing plants (Nyamakwere *et al*., 2017). Slaughterhouses play a crucial role in the surveillance, control, prevention and eradication of animal-borne diseases. These diseases can originate either from animals infected during the ante-mortem phase or from contamination occurring during the slaughtering process after death. To effectively control and prevent cross-contamination of carcasses and meat with food hazards, slaughterhouse hygiene practices must be maintained throughout the slaughtering and dressing process, up to and including refrigeration (Nastasijevic *et al.*, 2022).

Common health risks to meat consumers include contamination from meat handlers, animal skin, the animal's gastrointestinal tract and the meat processing environment (CAIFS, 2024). The study conducted by Nurye and Demlie (2021) showed that inadequate hygiene practices allow consumers to be exposed to pathogens that cause public health problems. Poor establishment and hygiene practices in meat production lead to contamination of meat. The Codex, General Principles of Food Hygiene, defines food hygiene as a set of conditions and measures necessary to ensure food safety and suitability at all stages of the food chain. Well-implemented prerequisite programs, including Good Hygiene Practices (GHP), Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP), as well as training and traceability, should be the basis of an effective HACCP system (Alimentatius, 2022).

2.7.2. Water quality in slaughterhouse operations

Water is a vital component in the food sector and performs various important functions. It is crucial in food manufacturing as well as in cleaning, sanitation and manufacturing processes. In addition to being present in food, water is used for purposes such as irrigation, unloading, washing, rinsing, salting and ice production. The quality of water can be of utmost importance in both products and processes in the context of food production systems. But, sadly, it's often an overlooked critical process leading to challenges such as inefficient water use, equipment shutdowns, lost revenue, risk to food safety, and lower product quality (Bhagwat, 2019).

Water treatment and disinfection before and after the use in Abattoirs are an important action in food processing plants. As water is available in various sources which may contain various types of impurities. This makes the water unable to be used directly for various purposes, before removing the impurities (Hashim, 2021).

In the food processing, including abattoir the water used for different purposes must fulfill drinking quality standards for contamination prevention and to meat product safety. Furthermore water sources such as Borehole or surface water if poorly managed or untreated can introduce pathogens into the food chain; this highlights the need for regulatory monitoring and follows water quality standards in line with ISO 22000 food safety management systems. Hence in abattoir keeping high water quality is not just a requirement of regulation but an essential factor of public health problems (WHO 2017).

2.7.3. Implementation of Hazard Analysis and critical Control Point

Hazard Analysis and Critical Control Points (HACCP) is a globally accepted, systematic and scientific approach to food safety for eliminating biological, chemical and physical hazards at every stage of the food chain (from primary production to final consumption). By adopting a HACCP approach the control measures must be undertaken on significant risks instead of only inspection and testing of final products. A food business should only introduce HACCP once it is aware of and has established good prerequisite programs for food safety management such as Good Hygienic Practices (GHP) (FAO, 2010).

Hazard Analysis and Critical Control Points System is a preventive tool to ensure safe production and wholesome food products. It is based on the combined utility of technical and scientific standards for a meat production process. The application of HACCP allows the manipulation of elements that affect the meat product and the process. This is a risk control mechanism in which food protection is addressed through the assessment and treatment of biological, chemical, and physical hazards throughout the meat production process (Mustefa, 2021).

The HACCP plan includes the following seven steps: carry out a risk analysis; define critical control points (CCPs); set critical limits; creation of monitoring system; determine the corrective actions to be taken when monitoring indicates that a particular CCP is not under control; establish verification procedures to confirm that the HACCP system operates effectively, and create documentation of all procedures and appropriate records for these principles and their implementation (Jackowska-Tracz *et al*., 2018; FDA, 2022).

In Ethiopia, while export abattoirs can handle livestock, large animal facilities are inadequate and hygiene practices are often poor in non-export abattoirs. There is no system of carcass quality grading or meat grading or labeling, which limits the economic benefits for the meat industry. In addition, animals are stressed during slaughter, raising hygiene concerns due to excessive water and blood flow, and there is insufficient information on food safety regulations (Mustefa, 2021).

2.7.4. Training and awareness Level among Meat Handlers

Foods intended for human consumption, especially those of animal origin, are particularly dangerous if food safety regulations are not respected (Aluko *et al*., 2013). As butchers and slaughterhouses are labor-intensive workplaces, the knowledge and level of training of meat processors on proper hygiene management and key control points in the food chain are essential to reduce health risks to meat consumers (Haileselassie *et al.*, 2013).

Consumer awareness of proper food handling in accordance with manufacturer recommendations contributes substantially to food safety (Sofos, 2014). Given the essential role played by butchers and meat vendors in food safety, meat handler also mandatory to have food safety knowledge, attitudes and practices (KAP) in order to develop interventions accordingly. Studies conducted by Abunna *et al.* (2022) in different regions of Ethiopia have revealed that the behavior of meat handlers is an important risk factor for food contamination and can reduce the quality of food served for human consumption.

Due to regulations inadequate food safety, poor hygiene and food handling procedures, weak regulatory systems, lack of funding for protective equipment, and lack of training of food handlers, foodborne microorganisms pose a greater threat to public health in developing countries. In eastern Ethiopia, meat processors had little knowledge of foodborne pathogens, time and temperature controls to prevent bacterial growth, cross-contamination, and the difference between cleanliness and hygiene (Tegegne and Phyo, 2017).

2.7.5. Regulatory Framework and Enforcement

Regulatory framework is important for food and food products produced, imported and exported into a country to maintain quality and safety of food in order to protect public health, meet consumer demands and expectations, generate foreign currency earnings, and maintain the trust and confidence of food trading partners. Therefore, when products are produced, imported or exported into this country, be they primary or secondary food products, governments will be ensuring that quality and safety is maintained (Temesgen and Abdisa, 2015).

Codex Alimentarius (often known as “Codex”), the primary objective of Codex is to protect consumer health and ensure fair trade practices in the food trade" (FAO and WHO, 2019a).

Specifically designed to assist countries to use in developing their food laws, even the an importance of agri-food systems in responding to environmental changes, focusing on the digital economy, emerging food chain risks, along with methods to mitigate challenges related to food transformation, and promotion of the One health approach, FAO and WHO recognize the value of evidence-based food-corridor systems to support the United Nations Sustainable Development Goals (FAO, 2023).

Slaughterhouses should be well aware of the regulatory requirements that govern their activities. Typically, the regulations will apply to several aspects of the slaughtering and further processing of animal meat as they applicable to animal welfare, food safety, sanitation, waste disposal, labeling, and worker safety. In knowing the relevant laws and standards, slaughterhouses are in a position to take steps that will encourage compliance with regulations beginning with the design of a slaughterhouse (Anonymous, 2023a). It is therefore necessary that food safety management measures should be implemented during slaughtering and meat processing to reduce the chances of contamination and to ensure the production of high quality meat such as Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and Standard Operating Procedures (SOP) as well as the Sanitation Standard Operating Procedure (SSOP), which explains the steps a facility must take to clean and sanitize all meat contact and non-product surfaces. Another important regulation is the food protection program which is developed to protect food, including meat, from being harmful to consumers by including safety protocols to prevent intentional acts of adulteration (Ahmed and Al-Mahmood, 2023).

2.7.6. A product recall and traceability system

A product recall and traceability system in food safety has long been a priority. In the food value chain, food source documentation is equally important, as it can be used to trace the origin of the food. This is where the concept of traceability comes from. Not only can traceability reduce food theft, but it also provides consumers with transparency and security. Traceability, according to Espieira (2016), is the ability to identify the origin (one step back) and the destination (one step forward) of food at every stage of the food chain, from production to distribution. It documents and connects the production, processing, and distribution chains of food materials and products.

Establishing a national food recall system is essential for an effective national food control framework, and it should not be hindered by the lack of a well-developed system. Key considerations include the necessity for multi-sectoral coordination among various agencies at the national level, as well as a tiered approach that clearly defines roles and responsibilities across different government levels, especially in countries with shared food safety responsibilities. It is crucial to establish clear recall terminology to ensure consistency and understanding among all stakeholders, recognizing that definitions may vary internationally. A food recall should be viewed within the broader context of risk management strategies employed by competent authorities in collaboration with the food industry. Additionally, the system must address a range of issues, including unsafe food, noncompliance, and suitability, while considering the complexity of food supply chains, which can impact recall execution. Finally, given the globalization of food supply, there is an urgent need for international collaboration and information exchange to enhance the effectiveness of national food recall systems (WHO, 2012).

Nevertheless, the pressure for traceability rapidly became consumer demand to know more about the animals from which their food was derived. It became more than a health issue consumers needed to know more about the circumstances under which animals were raised, how they were transported, how they were slaughtered. In general traceability is now no longer purely a health issue, but a marketing tool designed to give the consumer assurance that the product he/she is consuming is both safe and ethically acceptable (FAO/WHO, 2004).

3. MATERIALS AND METHODS

3.1. Study area

The study was conducted from November 2024 to April 2025 in Addis Ababa (AA-K and AA-Kal), and around (Bishoftu (B-M and B-P), and Mojo (M-M and M-P)), all situated within Central Ethiopia. These areas are characterized by varying ecological and climatic conditions with Addis Ababa having an elevation of 2330 meter with a longitude and latitude of 38.75º and 9.08º (with lowest and the highest annual average temperature of between 11 and 23 °C). Bishoftu is situated approximately 45 km southeast of the national capital and has a mild subtropical highland climate. The other location is Mojo located around 70 kilometers, southeast of Addis Ababa, falls under semi-arid to sub-humid climate (NMA, 2020) (Figure 1).

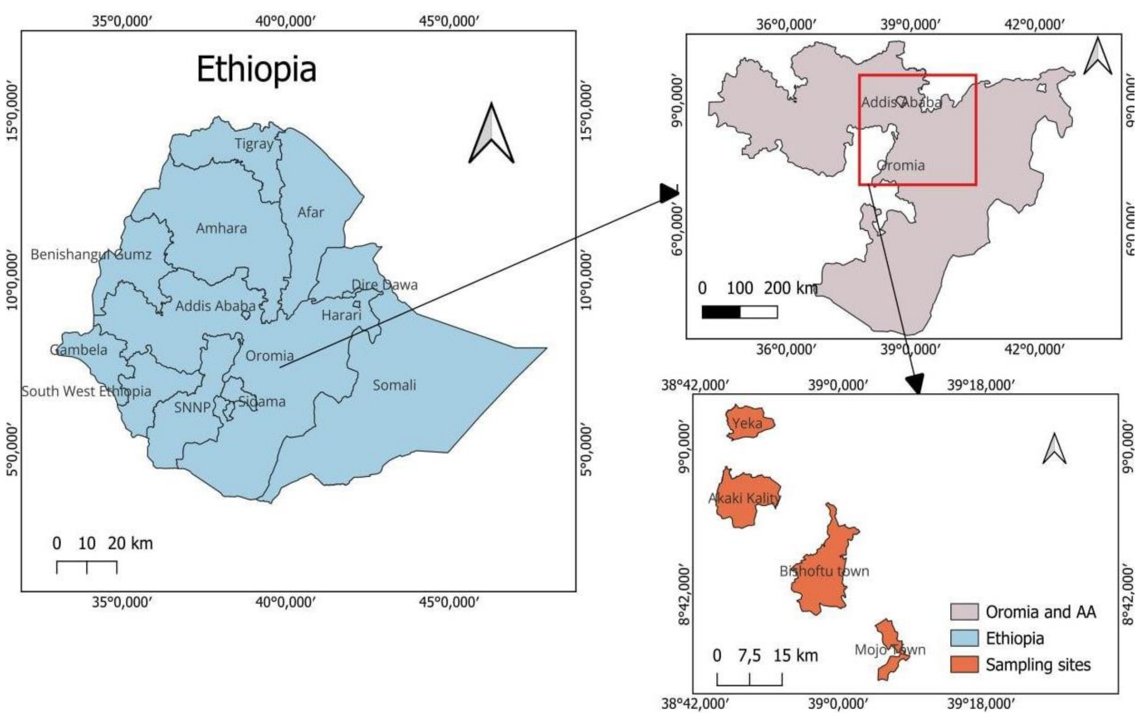

Figure 1: Map of study areas (created by QGIS 3.40.3 Desktop version software)

3.2. Study population

The target study population was slaughterhouses in Addis Ababa, Bishoftu, and Mojo towns. Slaughterhouse workers including meat inspectors (veterinarians and animal health workers), meat processors, sanitary personnel (cleaners), and managers were the sources of information in this study.

3.3. Study design

This study employed a cross-sectional design with a collection of data on hygienic practices, food safety management systems (FSMS) effectiveness, water quality, and microbial contamination prevalence in the Central part of Ethiopia.

3.4. Sample Size Determination

Sample size calculation was made for both questionnaire survey and sample collection for microbial analysis. Accordingly, the formula by Arsham (2002) was used to calculate the sample size as follows:

$n = 0.25/SE^2$, with a standard error (SE) of 0.05 and 95% CI; the sample was 100 participants.

To account for potential non-responses or data loss, the sample was increased to 110 participants. However, two of the data sets collected were excluded due to lack of completeness, which made the total sample 108. Those participants were asked for hygienic Practices and Food Safety Management System Assessment by face-to-face interviews and through direct observation on site. Furthermore, a total of 120 randomly selected samples were collected from carcass, equipment used in abattoirs (knife, axes and hooks), hand swab of personnel handling meat and water samples used in the abattoir for bacteriological analysis.

3.5. Sampling Procedures

The selection of abattoirs focused on capacity, accessibility and their active operational status. The selected abattoirs were mainly slaughtering cattle and all carcass swab samples were from cattle. All municipal abattoirs provide a slaughtering service for their respective town while the private abattoir were served according to the customer's order or market conditions including hotels, super markets and butcher shops. The daily cattle slaughtering rate depends on various factors, including fasting days and seasonal variations. Under normal circumstances, the slaughtering capacity ranges between 50 and 300 cattle per day, with a higher slaughtering rate observed in Addis Ababa compared to other abattoirs.

From those purposely selected abattoirs with the stated criteria, samples (carcass, equipment, and hand swabs) were randomly collected.

3.6. Data Collection and processing Methods

All abattoirs in the study area were visited 1-2 days before data collection to get permission and discussion on the study objectives with simple follow up questions of the abattoir routine slaughter schedule.

3.6.1. Questionnaire survey

The questionnaire surveys were done through a questionnaire designed for this purpose with kobo tool software. Additionally, a checklist was prepared to assess the food safety management system as well as the abattoir facilities through direct observation. The questionnaires and check-list were adapted from similar previous studies in Ethiopia (Haileselassie et al., 2013; Tegegne and Phyo, 2017; Gutema, 2021). This questionnaire was pre-tested and some changes and clarification was made where needed. Written informed consent had been read to the study participants and their full permission to involve in the survey was always granted before the start of the conversation (Annex I).

Slaughterhouse workers include meat inspectors (veterinarians and animal health workers), sanitary personnel (cleaners), managers and workers who have direct contact with carcasses. The number of abattoir workers in each study area was different depending on the abattoirs; human resources with a higher active personnel were higher in Addis Ababa followed by Bishoftu and Mojo. A total of 110 participants were planned to be collected though two of the collected data were discarded during the final data clean up which made the total to 108 participants. 34 from Bishoftu (20 from B-M and 14 from B-P), 34 from Mojo (18 from M-M and 16 from M-P) and 40 from Addis Ababa (23 from AA-K and 17 from AA-Kal abattoirs) were taken for the questionnaire survey for this study.

The questionnaires were administered to generate data about Hygienic Practices Assessment and Food Safety Management System Assessment. The questionnaire included socio-demographic characteristics of abattoir workers, presence of facilities, sanitation practice, receiving training, medical checkup, awareness about source of contamination, knowledge of FBDs are considered (Annex II). Additionally, observational analysis was made in the abattoir facilities to answer questions concerning equipment, the current status of hygiene and sanitation practices (GHP) in an abattoir, and food safety management and documentation of abattoirs. Observational approach into the abattoirs were made during their active slaughtering time (Annex III).

3.6.2. Swab sample collection

A total of 120 swab samples were collected from 6 slaughterhouses from three towns; two abattoirs per city administration. It is obviously known municipal abattoirs in the all city administration included in this study except Addis Ababa, owns a single abattoir. Additionally, the number of private abattoirs designed to process meat for local consumption is limited. Taking this into account and the abattoirs where the questionnaire survey was made, laboratory sampling was taken. Accordingly, from each abattoir, 20 swab samples were taken from carcass, equipment, hands of abattoir workers and water used in the abattoirs and recording was made to identify specific samples, abattoirs and pathogens. A separate plastic bag was used for each samples to prevent cross contamination of samples taken (Annex IV).

Selected carcasses were swabbed using the method described in ISO 17604 (2005). A sterile cotton swab (2X3 cm) was first soaked in an approximately 10 ml of buffered peptone water (Oxoid Ltd., Hampshire, England) rubbed first horizontally and then vertically several times on specific sites of a carcass approximately 25 cm^2. The abdomen (flank), thorax (lateral) and breast (lateral) regions are sites with the highest rate of contamination as per ISO 17604, (2005). Additionally, the swabbing method was also applied for the collection of samples from equipment used in meat production (knives and hooks) and manipulator’s hands. Each swab was numbered appropriately, indicating the site and date of collection (Annex V). Those swab samples were shipped directly to the microbiology laboratory of the Ethiopian Agricultural Authority's Animal Product and Input Quality Testing Centers (EAA, APIQTC) with an ice box maintaining the cold chain followed by microbiological analysis following biosafety and biosecurity instructions. All microbiological analysis steps are kept under Annex VI.

A total of six water samples (i.e. the one used to clean the carcass) from each abattoir were collected and shipped to APIQTC for microbiological analysis in a similar way for the swab samples. Furthermore, physical, chemical and heavy metal detection was done on these waters at the African Center of Excellence for Water Management (ACEWM) laboratory at Addis Ababa University within 24 hrs of collection.

3.6.3 Microbiological analyses

Samples were analyzed immediately upon arrival at the laboratory (EAA, APIQTC). Bacterial load count, isolation and identification of bacteria as well as physicochemical and heavy metal analysis of water were performed at two laboratories (EAA, APIQTC and ACEWM). Bacterial analysis were made with bioMérieux TEMPO® and OmniLog ID System. The bioMérieux TEMPO® and OmniLog ID System are often chosen for microbial load enumeration and microbial identification, respectively, due to their automation, speed, and high-throughput capabilities.

Bacterial load count: upon arrival of swab samples at EAA, APIQTC, 90 ml of peptone water was added into each and every plastic bag containing swab samples followed by homogenizing with homogenizer for 15 seconds (APHA, 1992). Bacterial count is performed using the bioMérieux TEMPO® system consisting of two independent devices the TEMPO® Filler and the TEMPO® (BioMérieux, 2010). Following EN ISO 16140 standards for *E. coli, S. aureus* count and AP count 1 ml of diluted sample is added to a tempo vial containing dehydrated media specific for *E. coli* (TEMPO EC) and *S. aureus* (TEMPO STA), Aerobic count (TEMPO AC) respectively. Prior to sample addition, 3 ml of sterile distilled water was dispensed into each vial to rehydrate the culture medium. Each tempo vial was attached with the test card and placed in TEMPO® Filler and press "Start" to fill and seal the card. Each testing card was incubated at 37 °C for 24 hrs. After their respective incubation period, all cards were analyzed sequentially in an automated fashion using the TEMPO® reader station. The final results were reported in CFU/ml and interpretation determination with the cut off value for APC; *E. coli* and *S. aureus* were made as per the FAO (2007) guideline.

Isolation and Identification of bacteria: to isolate and identify *E. coli*, *S. aureus*, and Salmonella species, from the swab samples made with selective enrichment broths. For *E.coli* detection, 1 mL of the pre-enrichment sample transferred to EC Broth. Incubate at 44.5°C for 24 hrs then streak onto MacConkey/EMB agar for selective isolation of lactose-fermenting colonies (*E. coli* appeared pink due to lactose fermentation/ metallic green sheen colonies). Confirmation was done using an omnilog system. *E. coli* O157, Shiga toxin-producing *E. coli* (STEC) serotype, was also isolated and determined in this study.

For *Staphylococcus aureus*, directly streak the pre-enrichment sample onto MSA plates. Incubate at 35–37°C for 24–48 hrs and *S. aureus* colonies typically appeared yellow due to mannitol fermentation, while other organisms remain pink or red.

For Salmonella species 1 mL Transferred TT Broth (Tetrathionate Broth) and another 1 ml to RVS Broth (Rappaport-Vassiliadis Soya Broth). Incubate TT Broth: 37°C for 24 hrs and RVS Broth 42°C for 24 hour then Streak on XLD Agar (Xylose Lysine Deoxycholate)and Incubate at 37°C for 24 hours. Salmonella colonies appeared red with black centers (H2S production).

Identification was conducted using OmniLog ID System according to the manufacturer's instructions in the OmniLog ID System User Guide (Biolog, Hayward, CA).All isolates, are subcultured at 35°C on a Biolog Universal Growth (BUG) agar plate with 5% sheep blood. After an incubation period of 18 to 24 hr, a colony transferred to inoculating fluid with sterile wooden Biolog Streakerz™ stick .The cell density of the suspension is adjusted at 95% transmittance (T) using a turbidimeter. Using multichannel pipette the solution transferred to GENE III microplate, incubated and analyzed in the omnilog micro-station that provided the most probable identification of the bacteria.

3.6.4. Physicochemical and heavy metal analysis

For water analysis (both microbial, physic-chemical and heavy metal analysis), water samples of five abattoir were used in this study. The reason not to include one abattoir was because of untraceability of the water source as the abattoir used some other institutions water where the one supplying them was not interested for the samples to be tested. For both physicochemical and heavy analysis, the procedures are listed with Annex VII.

Physicochemical analysis: one liter of water sample was collected from each abattoir and transported directly to ACEWM laboratory for analysis. In the lab, physicochemical analysis of water was tested to check whether the used water is with acceptable pH, temperature, conductivity, total dissolved solids (TDS), and Salinity level using a portable combined instrument (HI-991300, Hanna® Instruments). Additionally, dissolved oxygen (DO) was measured directly using a DO probe while biological oxygen demand (BOD) analysis was assessed by filling a BOD bottle with a sample of water and placing it in an incubator 20°C for 5 days. Finally, DO level was measured at the beginning and after incubation period to determine the BOD. The other was COD analysis which was measured after taking 2 ml of sample water added to the COD vial then the sample was digested at 150°C for 2 hrs in the COD reactor (APHA 5220). After digestion, the vials were removed and allowed them to cool to room temperature then measured by spectrophotometer at around 600 nm.

Heavy metal analysis: Heavy metal analysis was conducted by an inductively coupled plasma-optical emission spectrophotometer (Agilent 5800 ICP-OES) equipped with Argon gas, Plasma, auxiliary, Nebulizer, and RF Power to determine the concentration of selected metals in sampled waters. For this study, lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and manganese (Mn) were harmful toxic metals checked in the water samples. The maximum permissible level of heavy metal was determined based on the guidelines given by WHO (2011).

First digestion was done by 10 mL of concentrated nitric acid (65% HNO_3) added to the digestion vessel containing 5 mL of the sample. This vessel was sealed and placed in a microwave digestion system at 180°C for 10 min then allowed to cool. Following EPA Method 3051A or APHA guidelines, the digested sample transfer to flask and diluted with deionized water and thoroughly mixed. Transfer diluted sample to auto-sampler vial then sample introduced to ICP-OES and analyzed and concentration were calculated in mg/L.

3.7. Data management

Data gathered from the study were entered into Microsoft excel spreadsheet followed by data curation (cleaning) and coding. Before coding, the results of microbial counts (CFU/ml) were converted into log10 and descriptive statistics were made to calculate frequencies and percentages of different factors included in this study (Questionnaire survey and laboratory analysis). Furthermore, statistical analysis was conducted using STATA version 15 to look at the association between the microbial loads and different abattoirs as well as samples with odds ratio. The significance levels of association were determined with $p < 0.05$ at 95% confidence interval.

3.8. Ethics approval

Ethical clearance was offered by the Animal Research Ethics Review Committee of the Addis Ababa University; College of Veterinary Medicine and Agriculture (ref. no. VM/ERC/04/77/17/2025) (Annex 8.9A) and Aklilu Lemma Institute of Pathobiology (ref. no. ALIPB IRERC/154/2017/24) (Annex 8.9B).

4. RESULTS

4.1. Questionnaire survey

4.1.1. Demography of participants

Questionnaire survey was made with kobo tools at six different abattoirs a total of 108 voluntary workers participants were interviewed. The demographic survey indicated the dominant number of male (59.26%), aged >35 years (58.33%), college degree (Diploma and above) (75%), and meat inspector (40.74%) roles (Table 1).

Table 1: The demographic characteristics of Abattoir workers respondents in Central Ethiopia (N = 108)

Variables	Category	Number (%)
Gender of respondents	Female	44 (40.74)
	Male	64 (59.26)
Age of respondents	≤35	45 (41.67)
	> 35	63 (58.33)
Educational level	Primary education	20 (18.52)
	Secondary education	7 (6.48)
	College (Diploma and above)	81 (75)
Role in the abattoir	Cleaner	11 (10.19)
	Slaughterer	16 (14.81)
	Meat inspector	44 (40.74)
	Supervisor	37 (34.26)

4.1.2. Abattoir hygiene and assessment of food safety management

The questionnaire survey showed a higher presence of hygienic protocol in the abattoir (83.33%) with 100% of these survey participants mentioning the requirement to wear personal protective clothing (Specifically clothes, boots and aprons). However, through observational study; gloves and hair net were not observed and even the aprons were too old in most of the slaughterhouse facilities. Furthermore, food safety management system analysis of the survey showed the presence of procedures in place for addressing non-compliance or food safety, presence of quality control measures in place to assess the safety and quality, and the presence of abattoir compliance with local and international food safety regulation in 38.89%, 5.56% and 22.22% of respondents, respectively (Table 2).

In water hygiene, 66.67% perform regular water testing, but less than half (44.44%) of the abattoirs have records of water quality tests, which indicated a lack of documentation. Infrastructure of abattoir while 61.11% had adequate drainage, only 27.78% well-ventilated facilities and 16.67% used non-porous, easily cleanable surfaces while 11.11% the presence of designated processing areas in their abattoirs. Cleaning practices varied, with 94.44% using cleaning agents, but only 44.44% followed the recommended cleaning procedures.

Table 2: Hygiene and food safety management assessment of abattoirs in Central Ethiopia (N=108)

Variables	Yes	No	Don't know
Food safety management system assessment			
Presence of hygienic protocol in the abattoir	90 (83.33)	18 (16.67)	-
Monitoring systems established to track food safety compliance	60 (55.56)	48 (44.44)	-
Presence of proper documentation of food safety procedures	72 (66.67)	36(33.33)	-
Are there procedures in place for addressing non-compliance or food safety (E.g. inspections, audits, sampling, HACCP verification, CCP monitoring)	42(38.89)	66(61.11)	-
Are there quality control measures in place to assess the safety and quality	6(5.56)	102(94.44)	-
Is the abattoir compliant with local and international food safety regulation	24(22.22)	84(77.78)	-
Training on food safety practices including Hazard Analysis (HACCP)	51(47.22)	57 (52.78)	-
Are staff required to wear personal protective clothing	108 (100)	0	-
Are there regular internal audits for hygiene practices?	42(38.89)	66 (61.11)	-
Are there corrective actions taken for identified hygiene issues? (E.g. documented correction such as training, supervisions etc)	54(50.00)	54(50.00)	-
Water hygiene			
Is the water used in the facility tested for quality and safety?	72(66.67)	24(22.22)	2(12)
Are there records of water quality tests available?	48(44.44)	54(50.00)	2(6)
Abattoir hygiene			
Is the abattoir facility well-ventilated?	30 (27.78)	78(72.22)	-

Are floors and surfaces in the slaughtering and evisceration areas made of non-porous materials that are easy to clean?	18(16.67)	84(77.78)	6(5.56)
Is there adequate drainage to handle waste and water runoff?	66(61.11)	42(38.89)	-
Are there designated areas for different processes (e.g., slaughtering, evisceration, waste disposal)?	12 (11.11)	90(83.33)	6(5.56)
Is the facility regularly inspected for structural integrity and cleanliness?	60(55.56)	48(44.44)	-
Is there a documented cleaning schedule for the facility?	42(38.89)	66(61.11)	-
Are cleaning agents and sanitizers used?	102(94.44)	6(5.56)	-
Are cleaning procedures followed as per the guidelines?	48(44.44)	54(50.00)	6(5.56)
Tools/utensils hygiene			
Are tools and equipment cleaned and sanitized after each use?	66(61.11)	42(38.89)	-
Is there a designated area for cleaning equipment?	12(11.11)	90(83.33)	6(5.56)
Are maintenance records for equipment available?	30(27.78)	78(72.22)	
Waste management			
Is there a proper waste disposal system in place?	36(33.33)	72(66.67)	-
Are waste containers covered and regularly emptied?	36(33.33)	72(66.67)	-

Respondents were asked to rate for some of the questions related to food safety management actions done in their abattoir premises. Implementation of hygienic protocol in the abattoir, training already taken in the past, food safety compliance implementations, food safety documentation in the abattoir, the implementations of procedures in place for addressing non-compliance or food safety, compliance with the implementations of local and international food safety regulations and the implementations of quality control measures in place to assess the safety and quality in the abattoir were assessed. Accordingly the last two indicators were shown to be the least frequently occurring phenomenon in their abattoir with a response rate of 6 and 18 respondents (Table 3).

Table 3: Rating of food safety management issues in selected abattoirs in Addis Ababa, Bishoftu and Mojo areas between November 2024 and April 2025.

Variables	Rating (implementations)			
	Rarely (Once/two per month)	**Sometimes (Once per Week)**	**Often (Several times per Week)**	**Always (Every time)**
Implementation of hygienic protocol in the abattoir (n=90)	6 (5.56)	42 (38.89)	22 (20.37)	20 (18.52)
Training implementation those who already took at least one training in the past (n=90)	3(3.33)	54 (60)	16 (17.78)	17 (18.89)
Rate food safety documentation in the abattoir (n=72)	0	42 (58.33)	18 (25)	12 (16.66)
Rate the implementations of procedures in place for addressing non-compliance or food safety (n=54)	0	18 (33.33)	0	36 (66.66)
How do you rate the implementations of quality control measures in place to assess the safety and quality (n=6)	0	0	0	6 (100)
Rate compliance implementations of local and international food safety regulations (n=18)		6 (33.33)	0	12 (66.67)

4.2. Microbial load

In this study, aerobic plate count (APC), *Staphylococcus aureus* and *Escherichia coli* load was determined in different carcasses, equipment, hands of meat handlers and water used in different abattoirs. Accordingly, the highest prevalence of APC was observed in water (83.33%), *S. aureus* in equipment (27.78%), and *E. coli* on the hands of meat handlers (51.43%). However, a lower proportion of APC and *E.coli* was recorded in equipment (50%) and carcass (27.87%), respectively while *S. aureus* was not found in inspected water (Table 4).

Table 4: Proportion (%) of bacterial count with unacceptable load from different samples of abattoir in Addis Ababa, Bishoftu and Mojo areas between November 2024 and April 2025.

Source	Number of samples collected	APC> limit (%)	*S. aureus* positive (%)	*E. coli* positive (%)
Carcass	61	32 (52.46)	13 (21.31)	17 (27.87)
Equipment	18	9 (50)	5 (27.78)	8 (44.44)
Hand	35	23 (65.71)	5 (14.29)	18 (51.43)
Water	6	5 (83.33)	0	2 (33.33)

The microbial count (log CFU/mL) revealed higher mean values for APC (6.46) and *Staphylococcus aureus* (1.78) in water and equipment, respectively. Meanwhile, both equipment and hands showed elevated mean counts for *E. coli,* each at 2.34 (Table 5).

Table 5: Microbial Counts (log CFU/cm² or CFU/mL) from different samples of abattoir and their personnel

Source	***No. of microbial counts in log CFU/ml***											
	APC				***S. aureus***				***E. coli***			
	Min	**Max**	**X̄± SD**	**SE**	**Min**	**Max**	**X̄±SD**	**SE**	**Min**	**Max**	**X̄±SD**	**SE**
Carcass	3.2	8	5.9±1.14	0.2	1	3.4	1.5±0.68	0.1	1	6.7	2.03±1.3	0.2
Equip	2	7.7	5.83±1.4	0.3	1	3.6	1.78±0.9	0.2	1	4.7	2.34±1.2	0.3
Hand	3	7.7	6.1±1.20	0.2	1	4.7	1.43±0.8	0.1	1	4.7	2.34±1.1	0.2
Water	5	7.7	6.46±0.9	0.4	1	1	1±0	0	1	3	2.01±0.9	0.5
Overall	2	8	5.99±1.19	0.1	1	4.7	1.5±0.75	0.07	1	6.7	2.16±1.2	0.12

The logistic regression analysis revealed a significant association in APC microbial load counts across most of the different abattoirs, with weaker associations observed for *S. aureus* and *E. coli.* However, among the various sample types, only *E. coli* from swab samples of abattoir workers' hands showed a statistically significant difference (p-value < 0.05) (Table 6).

Table 6: Logistic regression analysis of microbial load across different abattoirs from different samples

Variables (No.)	*Counts in log CFU/ml*											
	APC (N=69)				***S. aureus* (N=23)**				***E. coli* (N=45)**			
	No. (%) of unfit samples	**COR (95%CI)**	**AOR (95%CI)**	**p-value**	**No. (%) of unfit samples**	**COR (95%CI)**	**AOR (95%CI)**	**p-value**	**No. (%) of unfit samples**	**COR (95%CI)**	**AOR (95%CI)**	**p-value**
Abattoirs (20 samples for each abattoirs)												
B-P	13 (65)	Ref	Ref		1 (5)	Ref	Ref		3 (15)	Ref	Ref	
B-M	17 (85)	3.03 (0.66, 14.14)	3.13 (0.67, 15.15)	0.146	3 (15)	3.35 (0.32, 35.36)	3.43 (0.32, 36.93)	0.309	6 (30)	2.43 (0.51, 11.5)	2.54 (0.52, 12.5)	0.251
M-P	10 (50)	3.35 (0.32, 35.36)	3.4 (0.32, 36.47)	0.310	2 (10)	2.24(0.186 , 26.9)	2.21 (0.18, 27.04)	0.536	5 (25)	9.33 (2.18, 39.96)	10.87 (2.4, 49.28)	0.002*
M-M	19 (95)	5.56 (1.25, 25)	5.86 (1.26, 27.03)	0.024*	4 (20)	5.85 (0.58, 58.43)	6.1 (0.59, 62.44)	0.128	16 (80)	1.29 (0.32, 5.18)	1.22 (0.29, 5.15)	0.784
AA-K	7 (35)	10 (2.27, 47.62)	11.9 (2.44, 58.82)	0.002*	13 (65)	35.29(3.87 , 321.93)	43.71 (4.51, 423.3)	0.001 *	9 (45)	1.91(0.52, 7)	2 (0.52, 7.72)	0.313
AA-Kal	3 (15)	32.15 (5.56, 200)	40 (6.48, 243.9)	<0.001 *	0	-	-	-	6 (30)	1 (0.26, 3.87)	1 (0.25, 4.05)	1.000
Samples (No. of positives)												
Carcass (n=61)	32(52.46)	Ref	Ref		13(21.31)	Ref	Ref		17(27.87)	Ref	Ref	
Equipment (n=18)	9 (50)	1.1(0.38, 3.13)	1.17 (0.32, 4.29)	0.810	5 (27.78)	1.33(0.4, 4.43)	1.52(0.34 , 6.72)	0.582	8 (44.44)	2.07(0.7, 6.13)	2.47(0.73, 8.36)	0.146
Hand (n=35)	23(65.71)	1.74(0.74 , 4.1)	2.24(0.78, 6.48)	0.136	5 (14.28)	1.68(0.54, 5.2)	2.21(0.55 , 8.82)	0.262	18 (51.43)	2.74 (1.15, 6.53)	3.42(1.28, 9.15)	0.014*
Water (n=6)	5 (83.33)	4.53(0.5, 41.1)	8.33(0.66, 105.6)	0.102	0		-	-	2 (33.33)	1.3(0.22, 7.73)	1.37(0.18, 10.29)	0.758

'-' all samples from this specific abattoir was fit for consumption due to low bacterial count, '*'- statistically significant, 'COR'- Crude odds ratio, 'AOR'- Adjusted odds ratio, 'Ref'- reference, 'CFU'- Colony forming unit

4.3. Isolation and identification of pathogens

Bacterial isolation was made from different samples (Carcass, equipment, hands and water) taken from the six abattoirs in Central Ethiopia. Isolation was followed by identification of major pathogens (*S. aureus, E. coli, E. coli* O157:H7 and Salmonella) known to have a food safety concern as they affect consumers. The highest proportions of samples with pathogens were 75.41%, 14.75% and 6.56% for *E. coli, E. coli* O157:H7 and *Salmonella, respectively,* in carcasses of different abattoirs. However, *S. aureus* was identified more on hands of abattoir working personnel (33.33%) than other samples. Overall, the percentage of identified pathogens was highest for *E. coli,* ranging from 37.14% to 75.41% across the six sampled abattoirs. Notably, *E. coli* O157:H7 and *Salmonella* were absent in samples collected from one and four abattoirs, respectively (Table 7).

Table 7: Identified food pathogens from different sources in six abattoirs from Addis Ababa, Bishoftu and Mojo areas between November 2024 and April 2025 (N=120)

Variables	**No. of identified pathogenic bacteria (%)**			
	E. coli	***E. coli* O157:H7**	**Salmonella**	***S. aureus***
Samples (No.)				
Carcass (61)	46 (75.41)	9 (14.75)	4 (6.56)	15 (24.6)
Hand (18)	12 (66.67)	1 (5.56)	0	6 (33.33)
Equipment (35)	13 (37.14)	0	0	0
Water (6)	3 (50)	0	0	0
Abattoirs (n= 20 for each abattoirs)				
B-M	15 (75)	3 (15)	2 (10)	4 (20)
B-P	14 (70)	0	0	3 (15)
M-M	12 (60)	2 (10)	0	6 (30)
M-P	9 (45)	1 (5)	0	2 (10)
AA-K	16 (80)	3 (15)	2 (10)	3 (15)
AA-Kal	8 (40)	1 (5)	0	3 (15)

E. coli- Escherichia coli, S. aureus- Staphylococcus aureus

4.4. Water quality

For water quality assessment (phsico-chemical properties and heavy metal detection) was made with water samples taken from five abattoirs.

4.4.1. Physico-chemical properties

Water samples from 5 abattoirs were checked for their physico-chemical properties. Accordingly, most (pH, temperature, conductivity, TDS) of the physico-chemical properties of checked water were under the normal range, i.e. acceptable figure. However, salinity levels in all abattoirs exceed the permissible limit which may affect meat quality and equipment. These could be due to its interfere with cleaning and sanitizing effectiveness (e.g., reduces efficacy of disinfectants), may attract certain bacteria and physiochemical changes in the meat (e.g., altered pH, faster spoilage) (Table 8).

Table 8: Physico-chemical properties of water collected from different abattoirs of Addis Ababa, Bishoftu and Mojo areas between November 2024 and April 2025

Source	pH	Conductivity (µS/cm)	Temp (°C)	TDS (ppm)	Salinity (%)	COD	BOD	DO (mg/L)
AA-Kal	7.75	1137	20.7	575.8	1.60	ND	3.1	5
M-M	7.67	764	20.4	382.2	1.50	ND	2.1	4.6
B-P	7.61	851.5	20.6	425.6	1.70	ND	1.71	4.5
AA-K	7.71	517.7	22.2	266	1.00	ND	1.13	4.38
M-P	7.78	775.7	20.9	405	1.50	ND	2.3	4.6
Normal range	**6.5-8.5**	**<1500**	**20-25**	**<1000**	**<0.5**	**<10**	**<3**	**>2**

ms-millisiemens, COD- chemical oxygen demand, BOD- Biological oxygen demand, DO- Dissolved oxygen, TDS- Total Dissolved Solids, ND- not detected

4.4.2. Harmful toxic metals

Harmful toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and manganese (Mn) were assessed in water samples taken from the five abattoirs. Among six harmful toxic metals analyzed; Pb, Cd and Mn were observed to be high in at least one abattoir’s water. From these lists, Cd was detected in higher amounts in all five abattoirs while Pb and Mn were seen to be high in one and two abattoirs, respectively (Table 9).

Table 9: Detected harmful toxic metals in five abattoirs in Addis Ababa, Bishoftu and Mojo areas between November 2024 and April 2025

Tested harmful toxic metals	Maximum permissible level of harmful toxic metals	Abattoir names				
		AA-Kal	M-M	B-P	M-P	AA-K
Pb (ppm)	0.01	7.50 u	5.61	-2.9u	0.31u	6.49u
Cd (ppm)	0.003	2.50	2.20	2.38	1.83	2.65
Cr (ppm)	0.05	-3.03 u	-4.81 u	-1.78 u	-3.34 u	-6.26 u
Cu (ppm)	2	-0.75 u	-6.99 u	-3.44 u	4.01 u	8.06 u
Mn (ppm)	0.5	1.87	0.45 u	-0.66 u	1.93	0.88 u

u = below detection limit (unquantifiable)

5. DISCUSSION

In the meat processing sector, food safety is of utmost importance, especially in abattoirs, where the primary sources of microorganisms include the animal's skin, surfaces that come into contact with meat such as different equipment used in the abattoir (tables, axes, hooks, scales, and knives). Additionally, clothing and hands of the personnel involved in meat processing are the common sources of contamination in this processing industry. Ensuring the safety of meat products is critical to safeguarding consumers from foodborne diseases and promoting public health (Chutia *et al*., 2019). Taking this into consideration the current study was conducted by assessing slaughterhouses through observational, questionnaire survey and laboratory assessment of microbials (load and identification) from different samples.

The questionnaire survey showed different demographic features of abattoir workers (Table 1) dominated by male (59.26%), aged >35 years (58.33%), college degree (Diploma and above) (75%), and meat inspector (40.74%) roles (See table 1). The study by Gadisa *et al.* (2019) and Nwoye *et al.* (2022) found an even more dominant number of abattoir workers by male with 91.12% and 85%, respectively. Another study Zelalem *et al.* (2021) also found a dominant number of male (94.3%) personnel from abattoirs taken from different parts of Ethiopia. However, they found out the college degree holders of 7.1% in Eastern Oromia of Ethiopia and even a much lower number (0.83%) than the current findings were in Nigeria (Nwoye *et al*., 2022). This can be justified by targeted selection of respondents and focus to professionals rather than daily laborers in the current study to analyze the food management systems of the abattoir.

Due to Ethiopians cultural traditions of raw or undercooked meat consumption, meat safety has become a huge issue (Beyi *et al*., 2017). Most of the respondents responded positively for the presence of hygienic protocol in the abattoir (83.33%), monitoring systems established to track food safety compliance (55.56%), and presence of proper documentation of food safety procedures (66.67%). Additionally, 100% of this survey participants responded to wear personal protective clothing, boots, and aprons, but not include the use of gloves and hair covers. Through observational study, at least one abattoir workers used unclean and old aprons in their slaughterhouse facilities. This result lines up with Bersisa *et al* (2019) and Zelalem *et al.* (2021), finding reported that abattoir workers in Ethiopia show moderate to good hygiene practices. These include consistent use of personal protective equipment (PPE) such as gloves, aprons, and boots, as well as adherence to basic hand hygiene protocols. The researchers highlighted that while many workers understood the importance of hygiene in preventing contamination and disease transmission, gaps still existed in areas such as handwashing frequency, equipment sanitation, and proper disposal of waste. Factors such as limited access to clean water, inadequate training, and insufficient supervision were identified as challenges to achieving consistently high standards of hygiene. These findings suggest a relatively commitment to basic hygiene guidelines in terms of protection and visible sanitation policies. These basic steps are crucial in countering bacterial contamination during the slaughtering process as they can be a potential source of different pathogens with a public health significance (Curtis and Cairncross, 2003; Nyamakwere *et al*., 2016; Nyamakwere *et al.*, 2017).

Most (52.78%) respondents mentioned lack of training on food safety practices including hazard analysis critical control point (HACCP). This finding is supported by the previous findings of Haileselassie *et al*., (2013), Birhanu and Minda (2017), Bersisa *et al* (2019) and Gutema (2021) who showed a significant proportion of meat handlers in abattoirs did not receive training on the hygienic handling of meat in Ethiopia. Food safety training should be provided to employees in food establishments such as slaughterhouses (Sun and Ockerman, 2005). This is the recommendation made by FAO to improve skills of abattoir personnel for the benefits of public health (FAO, 2019). Furthermore, training of personnel working in food processing plants with concepts and requirements of hygiene is crucial in ensuring the safety of their products from public health perspectives (Adams and Moss, 1997).

In the current study, microbial count, and identification were made on different samples collected from different abattoirs located in Central Ethiopia. Aerobic plate count is a method in microbial analysis where it generally measures microbial load of samples as a general measure of the microbiological status of meat (Anonymous, 2006). Microbial count analysis showed the overall higher mean aerobic plate count (APC) ($\bar{X}\pm$ SD; 5.99±1.19 log10 CFU/cm^2) followed by *E. coli* (2.16±1.2 log10 CFU/cm^2) and *S. aureus* (1.5±0.75 log10 CFU/cm^2). The current APC finding were found to be slightly higher than the findings of Gebeyehu *et al.* (2013) (5.21±0.47 log10 CFU/cm^2), Bersisa *et al.* (2019) in Bishoftu (4.53± 0.74 log10 CFU/cm^2), Haileselassie *et al.*

(2013) from Mekele. The other count was made for *E. coli* and *S. aureus* which was lower than the one reported by Gebeyehu *et al* (2013) (*S. aureus* (5.74±0.46)) at Adama town, Ethiopia.

The current study specifically made microbial load determination between different samples which showed higher APC count in water (6.46±0.9). However, Bersisa *et al.* (2019) (2.4 log10 cfu/ ml), Pius (2013) (4.3 log10 cfu/ml), and Tarwate *et al.* (1993) (2.1 log10 cfu/ml) reported lower total mean value than the current findings. The variations can be associated with the difference in the quality of water used at these different abattoirs.

In contrast to the current finding of water as a dominant sample with higher microbial load, Laban *et al* (2021) got higher bacterial counts from different samples than water (i.e. swab samples collected from slaughterhouses workers' hands). The current study necessitates the need to access quality water as far as public health safety concerns which needs to be healthy and safe to use (WQMS, 2017; FAO and WHO, 2023b). The other count was made for *S. aureus* which was higher in equipment used in abattoirs (1.78±0.9). This really put the health of public health under scrutiny as *S. aureus* is a major foodborne pathogen due to its ability to produce heat-stable enterotoxins (SEs) that withstand cooking temperatures **(**Shrestha *et al*., 2024; Elshebrawy *et al*., 2025). The third microbial count made in this study was *E. coli* count which was higher in both slaughterhouse equipment and hands of meat handlers with mean and standard deviation of 2.34±1.1. This is actually logical as *E. coli* commonly found on animal bodies via fecal contamination during slaughtering processes which even further made a cross-contamination in food preparation environments via improperly sanitized utensils or surfaces (Kintz *et al*., 2017).

Microbiological analysis of this study showed that aerobic plate count (APC) in different samples (carcass, equipment, hand and water) has shown significant differences among different abattoirs. Furthermore, abattoirs from Addis Ababa showed significantly lower unfit level of APC count while abattoir (M-M) from Mojo showed higher compared to the one sampled from Bishoftu ($p<0.05$). This contradicts with the findings of Alegbeleye *et al.* (2024), who reported slaughterhouses in Addis Ababa widely use unregulated groundwater due to municipal water scarcity, posing a high risk of microbial contamination while explaining their higher count. This justification could work to the places where the current finding of microbial count was found to be high.

Staphylococcus aureus, Escherichia coli, E. coli O157:H7 and *Salmonella* were important bacterial pathogens isolated in the present study. Cattle themselves from the contamination from their intestinal content and external contamination of carcass through different incidence during the processing with handlers and/or equipment used in the facility could possibly exist (Rombouts and Nouts, 1994). Swab samples collected from carcasses were high with *E. coli* being the most abundant (75.41%), followed by *E. coli* O157:H7 (14.75%) and *Salmonella* (6.56%). Relatively lower occurrence of identified *E. coli* was observed in carcass samples from different Ethiopian abattoirs (30.97% from Haramaya by Taye et al. 2013; 29.95% from Northwest Ethiopia by Abey, 2024; 23.4% from Wachamo by Tadese *et al*., 2021; 8.9% in Bishoftu by Gutema 2021). On the other hand, Hamid *et al.* (2018) reported higher percentage of *E. coli* in water samples (33.3%) compared to carcass (12%). The current finding also found water as the second most contaminated sample next to carcass samples. There could be a possibility for these contaminated water even be a source of contamination for carcass, majorly contaminates samples in this study. Additionally, unhygienic carcass handling, contamination of equipment used in the abattoirs during the operation can be a potential source of carcass contamination (Fasanmi *et al.*, 2010).

In the current study, the proportion of *E. coli* O157:H7 identified from different samples collected from different abattoirs of Central Ethiopia was 14.75%. Comparable results were published by Tizeta *et al.* (2014) (13.3%) and Gutema (2021) (12.3%) in different parts of Ethiopia. The later report was from samples taken directly from intestine which is the primary reservoir for *E. coli* O157, Shiga toxin-producing *E. coli* (STEC) serotypes (Gyles, 2007) and this pathogen resides in the gut of ruminants (Croxen *et al*., 2013). The existence of *E. coli O157* in cattle usually appeared to be asymptomatic except in newborn calves that causes occasional diarrhea in newborn calves (Pruimboom-Brees *et al*., 2000; Stein and Katz, 2017; Tourret *et al*., 2016). Shuhong *et al*., (2015) (13.3%) also reported a comparable percentage of *E. coli* O157:H7 from other parts of the world specifically China. The current result was higher than the reports of different researches done at different parts of the country (Gutema, (2021) (7.1%; in Bishoftu, Central Ethiopia), Tarekegn *et al.* (2023) (6.45% from Awi zone, Northwest Ethiopia); Atnafie *et al.* (2017) (2.4% from Hawassa, Southern Ethiopia); Taye *et al.* (2013) (2.65%; from Haramaya, Eastern Ethiopia), Tadese *et al*., (2021) (9.1% from Hosanna, Central Ethiopia Regional State); Haile *et al.*, (2017) (9.3%) and Mengistu and Eyob (2020) (5.4%) both from Jimma, Western Ethiopia), and Nega et al. (2021)

(9.1% from Ambo, West Central Ethiopia) from carcass samples. Additionally, similar findings were reported in other parts of the world, for instance, 7.86% in Iran (Zohreh, 2018), 6.5% in USA (Jamie *et al*., 2014), 2.3% in Egypt (Ahmed *et al*., 2017) and 0.2% in Nigeria (Mailafia *et al*., 2017). However, comparatively higher percentage of *E. coli* O157:H7 were found in different parts of the world including South Africa (Onyeka *et al*., 2021) (35.1%), Nigeria (Lennox *et al*., 2020) (60%), Iran (Momtaz and Jamshidi, 2013) (21.23%), 22% (Vinothkumar *et al*., 2014) and India (Vijayan *et al*., 2017) (25.46%). Overall variations in the occurrence of *E. coli* O157:H7 might be related to the level of contamination in different abattoirs.

Salmonella were isolated only from carcass 4/61 (6.56%) while the other samples from different equipment, hand and water in this study were all negative (0%). However, different researchers isolated Salmonella from different samples including carcass, equipment and hands of meat handlers from different Ethiopian abattoirs (Geresu *et al*., 2021; Tadesse *et al*., 2024). The prevalence of this study was comparable with the finding of Kebede *et al*. (2016) (5.7%) from Addis Ababa, and Gutema, (2021) (8.6%) from Bishoftu, Central Ethiopia; Sebsibe and Asfaw, (2020) (7.1%) from Jimma, Southwestern Ethiopia; Muluneh and Kibret (2015) (7.6 %) from Bahir dar, and Tadesse *et al*. (2024) (8%) from Dessie, Northern Ethiopia; Mekuriaw and Walelign (2016) (8%) from Wolaita Sodo, Southern Ethiopia. In contrary, a higher percentage was reported by Atsbha *et al*. (2018) (12.5%); Geresu and Desta, (2021) (14.29%); Hiko *et al*., (2016) (23.5%); Wabeto *et al.* (2017) (14.3%), and Zelalem *et al*. (2022) (22.7%) from different abattoirs located in different parts of Ethiopia. These observed variation to different locations could be due to carcass processing practices, abattoir facilities, personal hygiene, and handling which can significantly impact on the cross contaminations of carcasses (Gashe, 2022).

Staphylococcus aureus was found primarily on the hands of workers (33.33%). Comparatively, lower prevalence was reported by different researchers in different parts of Ethiopia (9.4% from Addis Ababa, Ethiopia by Adugna *et al*., 2018; 21.2% from Northern part of Ethiopia by Hailesilasse *et al*., 2013; 17.2% from Central Ethiopia by Gizaw *et al*., 2023; 19.3% from Asella by Abunna *et al*., 2016; 22.5% from Bishoftu by Bersisa *et al*., 2019) and Sudan (12% by Goja *et al*., 2013). However, higher prevalence was reported from Southern Ethiopia (40.6%) (Daka *et al*., 2012), Northern Ethiopia (39.1%) (Weldeselassie *et al*., 2020), Central Ethiopia (46.3%) (Beyene *et al*., 2017). These variations show a higher probability of human-sourced contamination with varied personal hygiene and sanitation protocols in different parts of the country. These variations can be due to the differences in spatiotemporal factors, hygienic practices and probable mixing of animals that play its own role in the distribution of this bacterium (Auguet *et al*., 2016; Gutema *et al*., 2021).

Generally by integrating hygiene practices from questionnaires, observational assessments, and laboratory-based microbial analyses. While 83.33% of respondents claimed adherence to hygienic protocols, direct observation revealed inconsistencies particularly in the proper use of personal protective equipment (PPE), execution of cleaning procedures, and maintenance of facility sanitation. Furthermore, microbial load data frequently opposed self-reported compliance. Several abattoirs demonstrating high levels of E. coli and S. aureus contamination also had inadequate documentation systems, infrequent internal audits, and a lack of corrective action processes.

These differences highlight potential biases in the survey responses or a lack of effective knowledge and oversight regarding actual hygiene practices. The observed gaps between reported and microbial results suggest that compliance may be superficial or poorly enforced. For example, some facilities that reported implementing an FSMS demonstrated microbial loads above acceptable limits, indicating a failure in practical application and monitoring. These findings underline the importance of combining surveys, observations, and laboratory results to evaluate food safety management systems more realistically and holistically. This integrated approach enhances the reliability of the conclusions drawn. It provides a comprehensive view of abattoir hygiene performance and identifies areas where improvements in training, infrastructure, and regulatory enforcement are needed.

Water sample use for carcass washing collected from the abattoirs was analyzed for their physico-chemical properties and heavy metal. The parameters such as pH, temperature, electrical conductivity, and total dissolved solids were the acceptable limits as recommended by international standards such as the WHO and FAO guidelines for potable and processed water in food establishments. Nevertheless, salinity levels in all evaluated abattoirs were above the permissible limits. This high level of salinity can impact meat quality, change the organoleptic properties, and contribute to the corrosion of slaughterhouse equipment, thereby affecting both food safety and sustainability operation.

Harmful toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and manganese (Mn) were assessed in water samples taken from the five abattoirs. Among six harmful toxic metals analyzed; Pb, Cd and Mn were observed to be high in at least one abattoir's water. From these lists, Cd were detected in higher amounts in all five abattoirs while Pb and Mn were seen to be high in one and two abattoirs, respectively. This finding must be supported by further investigation.

Regarding food safety and public health, the presence of harmful toxic metals in water used abattoir for different purposes can have severe implications. This Contaminated water may lead to the transfer of harmful metals to the meat products, posing risks to consumers. Furthermore, if this water is not properly managed, it is a threat to local ecosystems. Concerning heavy metal contamination in abattoir water the present study brings the serious need for strong monitoring and control measures. It is important for regulatory bodies to have strict rules and regulations to follow guidelines that confirm the safety of water used in the meat processing industry. Most both public health and the environment protection continuous research is required to identify sources of these contaminants and to develop mitigation strategies.

The environmental health implications of water quality are significant and must be systematically addressed to safeguard public health, reduce the transmission of waterborne diseases, and prevent the contamination of food sources. Poor water quality, especially in abattoir settings, poses serious risks not only to workers and consumers but also to the surrounding environment through the discharge of untreated effluents. Ensuring clean water throughout the meat production chain is essential for effective food safety management and aligns with the One Health approach, which recognizes the interconnectedness of human, animal, and environmental health.

The findings of this study highlight the strong interconnection between veterinary, public health, and environmental dimensions of One Health. Poor animal handling and slaughter practices contribute to the spread of zoonotic pathogens, affecting both meat safety and worker health. At the same time, contaminated water used in abattoirs and improper waste disposal pollute the environment, increasing risks to nearby communities. These risks underscore the need for coordinated efforts across animal health, public health, and environmental sectors to strengthen food safety through a One Health approach.

6. CONCLUSION AND RECOMMENDATIONS

This study indicates that contamination of carcasses in slaughterhouses is widely prevalent due to microbial contamination from environmental, meat handler, equipment and water used in the meat processing. The results showed that water samples had the highest bacterial loads, followed by equipment surfaces and hand swabs from meat handlers. Particularly, pathogenic bacteria such as E. coli, *Staphylococcus aureus*, and Salmonella were isolated from multiple sample types, posing serious public health concerns. In hand swab the highest contaminations are seen in with *E. coli*, which highlight the critical role of personal hygiene in preventing cross-contamination. Poor water quality, inadequate hygiene practices, and lack of effective food safety management systems (FSMS) were significant contributors to contamination. Many abattoirs have no proper sanitation infrastructure, documentation, and regular follow up/monitoring. Workers also show gaps in food safety knowledge and hygiene behavior, further aggravate the risks. With this, the following recommendations are forwarded:

- Strengthening of government regulatory authorities and enforcement of evidence-based laws and regulations.
- Awareness creation regarding the risk of lack of strict hygiene and cleanliness throughout slaughtering and dressing rooms
- Providing proper training for meat handlers on personal hygiene, safe meat handling, equipment use and cleaning, FSMS and adherence to regulations.
- Continuous monitoring and evaluation, including audits and inspections, and testing water quality to ensure all systems are functioning properly.
- Collaborative policymaking involving the Ethiopian Food and Drug Authority (EFDA), Ministry of Agriculture, and regional health bureaus is also critical to ensure coordinated implementation, monitoring, and enforcement across sectors.
- One health approach; application of one health in the abattoir that integrates human, animal, and environmental to effectively reduce foodborne risks along the meat processing chain.

7. LIMITATIONS OF THIS STUDY

The study's focus on a specific geographic area (Central Addis Ababa) limits the applicability of the findings to other regions in Ethiopia given the possible variations in infrastructure, resources, and regulations. One of the approach was questionnaire survey which is subjected to recall and personal judgement to the specific questions raised. Although key pathogens were identified, the study not have detailed characterization, specifically virulence gene assessment and antimicrobial resistance (AMR) profiling, which are essential for a comprehensive public health risk evaluation. The reliance on questionnaires introduces potential bias from abattoir workers. The absence of risk assessment limits the ability to draw definitive conclusions about public health risk levels. The study did not analyze data based on gender, job role, or training level, missing potential awareness into differential knowledge, practices, or risks among subgroups of abattoir workers. Resource and time constraints limited repeated sampling and follow-up monitoring, hindering the understanding of temporal trends and consistent compliance.

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8. ANNEXES

8.1. Annex I: Informed Consent

My name is Seble Aweke, I am working my MSc research at Addis Ababa University College of Veterinary Medicine and Agriculture (AAUCVMA). I am kindly requesting your participation in a short interview as part of my research about the 'Food safety management system and hygienic practice of slaughterhouses' and some parts of the study may involve physical observation, document review, and collection of swab samples from your hands, which aim to assess hygiene status with The ultimate goal is to identify areas for improvement of the slaughter house to safeguard the safety of carcass reaching consumer from slaughterhouses. All information that you give will be kept strictly confidential, your participation is voluntary, and you can drop it any time you want. If it is your permission to continue, please continue to the next section of interview.

Yes ____ No____(If the response is 'No', proceed with the other volunteer to participate in this survey)

Thank you for your participation!

8.2. Annex II: Questionnaire Survey

Questionnaire Code___________(numbered)
Name of enumerator______________________ Date of interview______________(D/M/Y)

BASIC INFORMATION OF THE FACILITY

Facility name_______________________ Facility established year____________
Region__________________ Zone______________________
District___________________ Town___________________
Address (Kebele)___________

PART One: DEMOGRAPHIC characteristics of respondents

1. What is the sex of respondents? A) Female B) Male

2. What is the age group of participants :_________(Put in number if they are volunteered to respond)

3. What is the educational status of respondents?

A) Illiterate (no formal education)
B) Primary school (1 to 8)
C) Secondary school (9 to 12)

D) Bachelor of science or Doctor of Veterinary Medicine
E) Others (Specify)________

4. What is the role assigned to the respondent in the abattoir?

A) Cleaner B) Livestock Slaughterer C) Supervisor/Manager

D) Meat inspector F) Others (Specify)_____________

PART-TWO: Evaluating Hygienic Practices in Abattoir

PERSONNEL HYGIENE

5. Are staff required to wear protective clothing (e.g., gloves, aprons, hairnets etc)?

A) Yes B) No

6. If 'Yes' to Question 5, how do you rate its implementations (1 to 4) [1 means rarely implemented (Once/two per month), 2-sometimes (Once per Week), 3- often (several times per Week), 4-always (Every time)] __________________________

7. Are staff trained in personal hygiene practices? A) Yes B) No

8. If 'Yes' to Question 7, how do you rate their training level (1 to 3) [1 means minimal training/refreshing, 2-Basics of personal hygiene practices in abattoir, 3-Advanced training on personal hygiene practices in abattoir]

9. How often do staffs wash their hands during operations? (Multiple Answers Possible)

A) Before starting work
B) After handling raw meat
C) After using the restroom
D) Other (Specify): _____________

WATER HYGIENE

10. Is the water used in the facility tested for quality and safety? A) Yes B) No C) Do not know

11. What type of water is used for cleaning and processing? (e.g., potable, non-potable)

A) Potable B) Non-potable

12. Are there record of water quality tests available?

A) Yes B) No C) Do not know

13. If 'Yes' to Question 12, specify the frequency of testing?

A) Every Day B) Every Week C) Every Month
D) Every Year E) Other (Specify)_____

ABATTOIR HYGIENE

14. Is the abattoir facility well-ventilated? A) Yes B) No

15. Are floors and surfaces in the slaughtering and evisceration areas made of non-porous materials that are easy to clean? A) Yes B) No

16. Is there adequate drainage to handle waste and water runoff? A) Yes B) No

17. Are there designated areas for different processes (e.g., slaughtering, evisceration, waste disposal)? A) Yes B) No

18. Is the facility regularly inspected for structural integrity and cleanliness?
A) Yes B) No

19. Is there a documented cleaning schedule for the facility? A) Yes B) No

20. How frequently is work surfaces cleaned?
A) After each use B) Daily C) Weekly D) Any other (Specify)________

21. Are cleaning agents and sanitizers used? A) Yes B) No

22. Are cleaning procedures followed as per the guidelines? A) Yes B) No

TOOLS/UTENSILS HYGIENE

23. Are tools and equipment cleaned and sanitized after each use? A) Yes B) No

24. Is there a designated area for cleaning equipment? A) Yes B) No

25. Are maintenance records for equipment available? A) Yes B) No

WASTE MANAGEMENT

26. Is there a proper waste disposal system in place? A) Yes B) No

27. Are waste containers covered and regularly emptied?

PART THREE: Food Safety Management System assessment

28. Is there hygiene and sanitation protocols for both the facility and the staff? (These include regular cleaning schedules and proper sanitation practices) A) Yes B) No

29. If 'Yes' to Question 28, how do you rate its implementations (1 to 4) [1 means rarely implemented (Once/two per month), 2-sometimes (Once per Week), 3- often (several times per Week), 4-always (Every time)]___________________

30. Are staff members trained in food safety practices, including Hazard Analysis and Critical Control Points (HACCP)? A) Yes B) No

31. If ‘Yes’ to Question 30, how do you rate their training level (1 to 4) [1 means rarely implemented (Once/two per month), 2-sometimes (Once per Week), 3- often (several times per Week), 4-always (Every time)]___________________

32. Are there monitoring systems established to track food safety compliance? [This includes temperature controls for meat storage, monitoring of cleaning procedures, and regular inspections of equipment]. A) Yes B) No C. I don't know

33. If ‘Yes’ to Question 32, how do you rate compliance implementations (1 to 4) [1 means rarely implemented (Once/two per month), 2-sometimes (Once per Week), 3- often (several times per Week), 4-always (Every time)]___________________

34. Is there proper documentation of food safety procedures, training records, and inspection results? A) Yes B) No C. I don't know

35. Are there procedures in place for addressing non-compliance or food safety issues?

A) Yes B) No C. I don't know

36. If ‘Yes’ to Question 35, how do you rate its implementations (1 to 4) 1 means rarely implemented, 2-sometimes, 3- often, 4-always]

____

37. Are there quality control measures in place to assess the safety and quality of meat products? [This includes testing for microbial contamination and ensuring that meat meets safety standards before distribution]. A) Yes B) No

38. If ‘Yes’ to Question 16, how do you rate its implementations (1 to 4) 1 means rarely implemented, 2-sometimes, 3- often, 4-always]

39. Is the abattoir compliant with local and international food safety regulations? [Compliance with established standards is a key indicator of a well-implemented FSMS].

A) Yes B) No

40. If ‘Yes’ to Question 18, how do you rate compliance implementations (1 to 4) 1 means rarely implemented, 2-sometimes, 3- often, 4-always]

8.3. Annex III. OBSERVATION CHECKLIST

Observation checklists	Presence/absence		Remarks
	Yes	No	
Overall cleanliness of the facility			
Condition and cleanliness of equipment			
Availability of handwashing stations			
Are staff members wearing appropriate protective gear?			
Compliance with personal hygiene protocols			
Frequency and thoroughness of cleaning practices			
Use of sanitizers and cleaning agents			
Monitoring of critical control points			
Evidence of corrective actions taken			

8.4. Annex IV: Document Review Framework

Essential Documents to Review (Check lists)

1) Food Safety Policy:
   - Check for a formal, Written policy
2) HACCP Plan:
   - Review for completeness and adherence to critical control points.
3) Training Records:
   - Assess training logs for staff and frequency of sessions.
4) Cleaning and Sanitation Logs:
   - Verify the maintenance of sanitation schedules.
5) Inspection Reports:
   - Analyze findings from previous health authority inspections.
6) Incident Reports:
   - Review any documented food safety issues and resolutions.

8.5. Annex V: Swab Sample recording formats

Date________________

Abattoir name____________, Region___________

District__________ City_______________

SN	**Sample**	No. of samples	Description	APC		*S. aureus* count		*E.coli* count	
				Count (CFU/g)	Interpretation	Count (CFU/g)	Interpretation	Count (CFU/g)	Interpretation
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

8.6. Annex VI: Steps followed for Microbiological analysis

Carcass Swab Sampling Procedure

- A sterile cotton swab (2×3 cm) was moistened with approximately 10 mL of buffered peptone water.
- The swab was rubbed over a defined surface area of the carcass using horizontal and vertical strokes.
- After sampling, the swab was placed in a sterile sample bag.
- Samples were immediately stored in an ice box and transported to the laboratory for analysis while maintaining the cold chain.

Steps of APC, *E. coli* (EC) and *Staphylococcus aureus* (SA) count

- For each 10 ml of food sample, 90 ml of buffered peptone water is added.
- Homogenize the sample with primary diluent (e.g., buffered peptone water)
- Label each sample and prepare for inoculation.
- Dispense 3 ml sterile distilled water into the EC culture medium vial, SA culture
- medium vial and 0.1 ml APC culture medium vial respectively
- Attached each tempo vial with the test card and placed in TEMPO rack
- Place the rack into the TEMPO® Filler and press "Start" to fill and seal the card.
- Incubate the card at 37°C for 24 hours.
- Insert the card into the TEMPO® Reader.
- Read and record results

Specification

Aerobic Plate Count-ES ISO 4833-1 10^6CFU/g

E-coli Count – ES ISO 16649-2 10^2CFU/g

Coagulase Positive Staphylococcus aureus – ES ISO 6888-1 10^2CFU/g

Isolation and Identification of Bacteria from carcass Swab Samples

Escherichia coli (E. coli)

- Add for each 10 ml of food sample, 90 ml of buffered peptone water and homogenized
- Incubate at 37°C for 18–24 hours

- Transfer 1 mL of pre-enriched sample into EC Broth.
- Incubate at 44.5°C for 24 hours.
- Onto MacConkey /EMB Agar Streak a loopful
- Incubate at 37°C for 24 hours.
- Pink colonies / metallic green sheen colonies /observed
- Confirm identity using the OmniLog ID System.

2. *Staphylococcus aureus*
   - Add for each 10 ml of food sample, 90 ml of buffered peptone water and hemognized
   - Incubate at 37°C for 18–24 hours for pre-enrichment.
   - Directly streak the pre-enriched sample onto Mannitol Salt Agar (MSA) plates.
   - Incubate at 35–37°C for 24–48 hours and yellow colonies identified.
3. *Salmonella* species
   - Add for each 10 ml of food sample, 90 ml of buffered peptone water and hemognize
   - Homogenize thoroughly and Incubate at 37°C for 18–24 hours for pre-enrichment.
   - 1 mL of pre-enriched sample transfer into Tetrathionate Broth (TT Broth) and incubate at 37°C for 24 hours and Rappaport-Vassiliadis Soya (RVS) Broth and incubate at 42°C for 24 hrs
   - From each broth Streak onto Xylose Lysine Deoxycholate (XLD) Agar.
   - Incubate plates at 37°C for 24 hours.
   - Identify red colonies with black centers

Bacterial Identification Using OmniLog ID System

- Isolates Subculture onto Biolog Universal Growth (BUG) Agar with 5% sheep blood.
- Incubate plates at 35°C for 18–24 hours.
- Transfer a colony from BUG agar to suspend in inoculating fluid.
- Using a turbidimeter adjust cell density suspension to 95% transmittance (T)
- using a multichannel pipette solution transfer to GEN III MicroPlate
- Incubate and place plates into the OmniLog® MicroStation for automated identification.
- System provides most probable bacterial ID based on phenotypic pattern

8.7. Annex VII: Water sample Analysis

A) Physicochemical Analysis

- Collect 1 liter of water sample
- pH, Temperature, Electrical Conductivity, Total Dissolved Solids (TDS) and Salinity measured by Immerse the probe of a portable combined meter (HI-991300, Hanna® Instruments) into the water sample
- DO (Dissolved oxygen) Measured directly using a DO probe by DO meter
- BOD Analysis:

- A BOD bottle was filled with the water sample.
- Placed in an incubator at 20°C for 5 days.
- DO measure at the start and after 5 days.
- BOD calculated as the difference between initial and final DO levels.

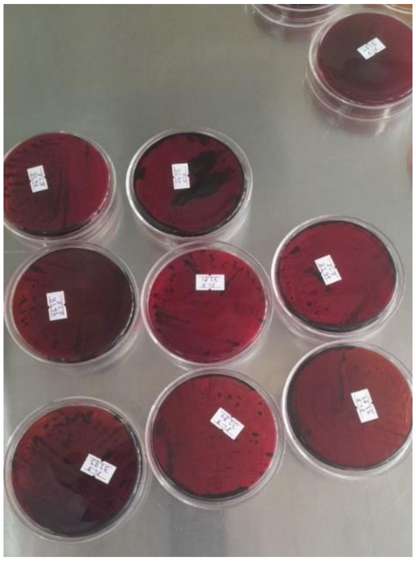
- Chemical Oxygen Demand (COD)

- Add 2 mL of sample water to a COD digestion vial.
- Digested at 150°C for 2 hours using a COD reactor
- Vials were cooled to room temperature.
- COD concentration measured using a spectrophotometer at ~600 nm

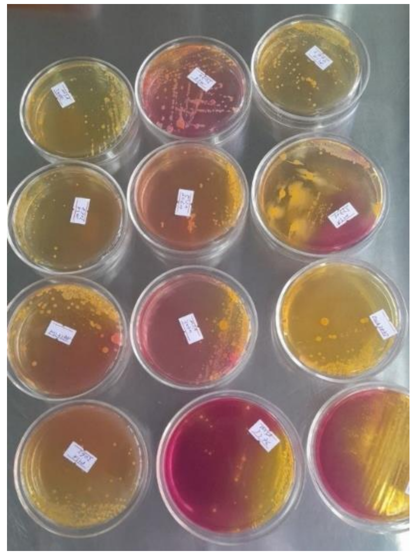
B) Heavy Metal Analysis

- Adde10 mL of concentrated nitric acid (65% HNO_3) to a digestion vessel containing 5 mL of water sample.
- Vessel seal and digest in a microwave digestion system at 180°C for 10 minutes.
- Allow to cool to room temperature.
- Digested sample transferee to a flask, diluted with deionized water, and thoroughly mix.
- Dilute sample transferee to an auto-sampler vial.
- Sample analyze using ICP-OES, and concentrations calculated in mg/L

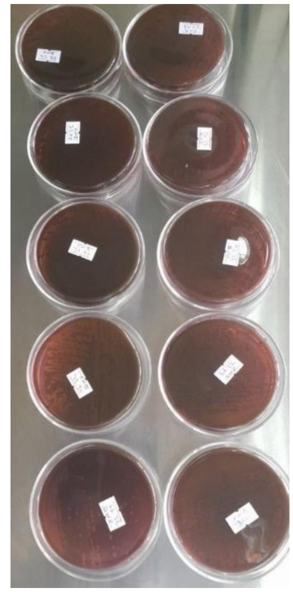
8.8. Annex VIII: Different pictures taken during the study periods



a) Some plates for Salmonella



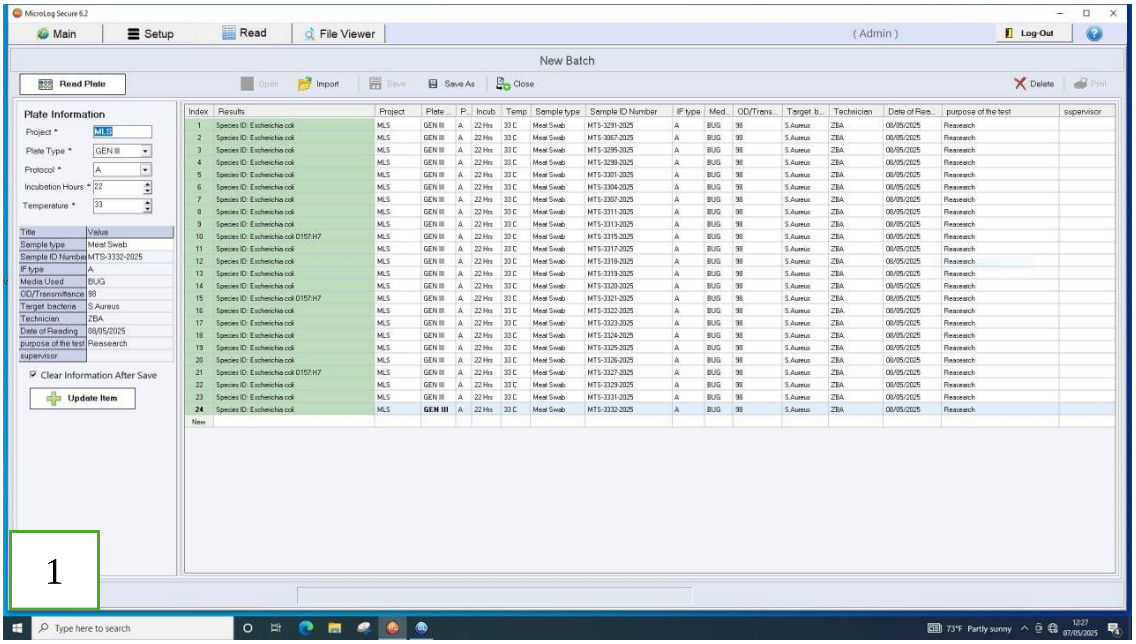
b) *S. aureus* bacteria on Mannitol Salt agar (MSA)

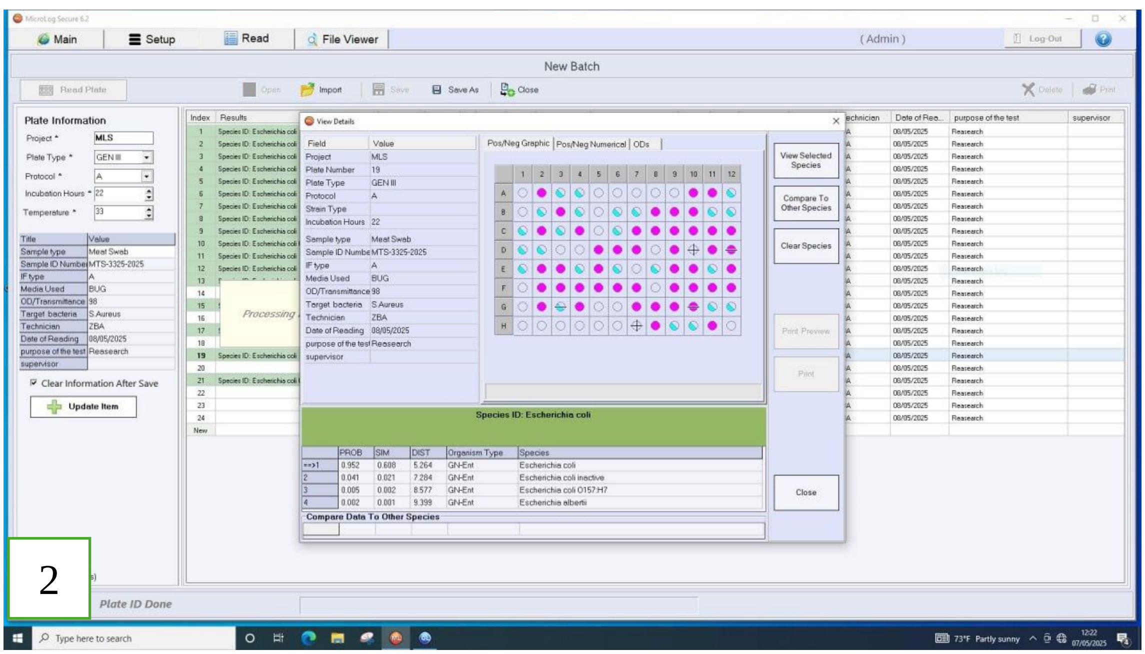


c) *E. coli* on EMB agar

d) Microbiological work under safety cabinet at APIQTC

e) Water analysis at ACEWM





g) Computer read of Gen III Micro plate all (1) and individual (2) E. coli O157:H7 isolate

h) Culture media vial for bacterial count

i) ICP for heavy metal detection

j) Auto-sampler for heavy metal detection

k) TEMPO® machine for bacterial count

l) OmniLog for bacterial identification

8.9. Annex IX: Ethical Clearance letters

A) Ethical clearance for sampling from abattoirs (CVMA-AAU)

ADDIS ABABA UNIVERSITY
College of Veterinary Medicine and Agriculture
Bishoftu

Animal Research Ethical Review Committee

Ethical clearance certificate

Certificate Ref. No: VM/ERC/04/77/17/2025

Name of Applicant: **Seble Aweke** (DVM, MSc student)

Address: Department of Microbiology, Parasitology and Poultry Health, College of Veterinary Medicine and Agriculture, Addis Ababa University

Title of the project: *Assessing food safety management systems: a one health approach to improve water quality and meat hygiene in Abattoirs in and around Addis Ababa*

Date of application:	**December, 2024**
Nature of the project:	**Abattoir investigation**
Target animal species:	**Cattle**
Number of animals involved:	**No live animal involved**
Study area:	**Addis Ababa, Ethiopia**

Minutes No. and date of review: **VM/ERC/04/17/025, 25/02/2025**

The Institutional Animal Care and Use Committee of the College of Veterinary Medicine and Agriculture of the Addis Ababa University has reviewed the above research project and unanimously approved the application of Seble Aweke.

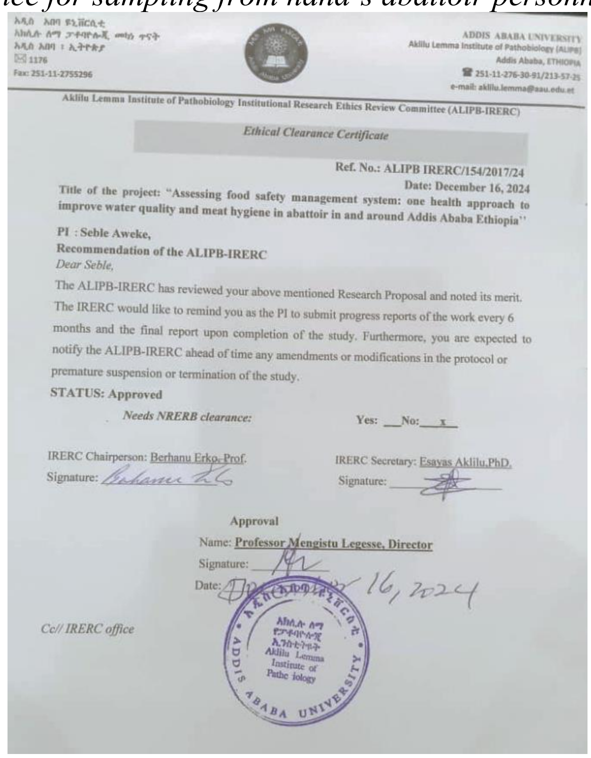
Professor Getachew Terefe (DVM, PhD)
Chairman

Signature

Please quote Our Ref. No. When replying

Fax 251-11-4339933 Tel. +251 114338450 P.o.x. Box 34 Bishoftu, Ethiopia

B) Ethical clearance for sampling from hand's abattoir personnels (ALIPB-AAU)



1176
Fax: 251-11-2755296

ADDIS ABABA UNIVERSITY
Aklilu Lemma Institute of Pathobiology (ALIPB)
Addis Ababa, ETHIOPIA
251-11-276-30-91/213-57-25
e-mail: aklilu.lemma@aau.edu.et

Aklilu Lemma Institute of Pathobiology Institutional Research Ethics Review Committee (ALIPB-IRERC)

Ethical Clearance Certificate

Ref. No.: ALIPB IRERC/154/2017/24
Date: December 16, 2024

Title of the project: "Assessing food safety management system: one health approach to improve water quality and meat hygiene in abattoir in and around Addis Ababa Ethiopia''

PI : Seble Aweke,
Recommendation of the ALIPB-IRERC
Dear Seble,

The ALIPB-IRERC has reviewed your above mentioned Research Proposal and noted its merit. The IRERC would like to remind you as the PI to submit progress reports of the work every 6 months and the final report upon completion of the study. Furthermore, you are expected to notify the ALIPB-IRERC ahead of time any amendments or modifications in the protocol or premature suspension or termination of the study.

STATUS: Approved

Needs NRERB clearance: **Yes: ___No:__x__**

IRERC Chairperson: Berhanu Erko, Prof.
Signature:

IRERC Secretary: Esayas Aklilu,PhD.
Signature:

Approval
Name: **Professor Mengistu Legesse, Director**
Signature:
Date: December 16, 2024

Cc// IRERC office

8.10. Annex X: Plagiarism report

Thesis title: ASSESSING FOOD SAFETY MANAGEMENT SYSTEM: ONE HEALTH APPROACH TO IMPROVE WATER QUALITY AND MEAT HYGIENE IN ABATTOIR IN AND AROUND ADDIS ABABA ETHIOPIA

MSc thesis

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