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BACTERIOLOGICAL AND CHEMICAL QUALITY OF WATER USED IN CARCASS WASHING IN KAJIADO SLAUGHTERHOUSES IN KENYA

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ABSTRACT

Washing carcasses with water at ambient temperature is a common decontamination intervention practiced across many small and medium slaughter facilities (SMS) in Kenya. While carcass washing is primarily done to enhance appearance by getting rid of visible contaminants, when poorly implemented, the intervention has the potential to become a source of contamination by introducing both spoilage and pathogenic bacteria, diminishing beef hygiene. The aim of this study was to investigate the bacteriological and chemical quality of slaughterhouse tap water used in washing beef carcasses in Kajiado slaughterhouses. Previous studies of slaughterhouse water quality in Kenya have not dealt with portable water, major focus being on quality of effluent prior to discharge. Total and faecal coliform, *Escherichia coli*, *Salmonella* and *Shigella spp*. in sampled water were examined with cultural methods. Water pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, Iron (Fe), aluminium (Al), fluoride, nitrate, nitrite and ammoniacal nitrogen were determined using several analytical instruments. Three out of five tap water samples (60%) tested positive for *E. coli* and *Pseudomonas aeruginosa* while one sample (20%) had isolates confirmed as having *Salmonella* species. Water sample temperatures ranged between 23.4 and 26.1 °C which were over the World Health Organization's (WHO) regulatory level of 20 °C. Forty percent of the samples exceeded Fe guidelines, recording 0.35 ppm (M3) and 0.24 ppm (M1C), with the latter also exceeding in EC (2533 ppm), and TDS (1260 ppm). One spring water (M1A) and one borehole water (M2A) sample had ammoniacal nitrogen and fluoride levels of 0.72 ppm and 2.05 ppm, respectively which were beyond the WHO regulatory limit. Aluminium and nitrate levels were low ranging from 0.027 to 0.059 ppm and 0.42 to 2.24 ppm, respectively. Nitrites were not detected. The study concluded that faecal contamination of water intended for beef hygiene and slaughterhouse sanitation operations raises public health concern for the presence of microbial risks including enteric pathogens and opportunistic infections. The study recommends sensitization of slaughterhouse management and local authority on role of water quality in slaughter operations and the establishment of sustainable water treatment and monitoring plans. Additionally, the study recommends further research to investigate seasonality of water quality and sustainable water treatment methods.

Key words: Slaughterhouse tap water, carcass washing, chemical water quality, faecal contamination

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INTRODUCTION

Water is a fundamental resource for the meat industry, playing a vital role in many applications including cattle washing, carcass decontamination, meat processing, hygiene and sanitation of personnel, equipment and the facility [1]. Underestimating the fundamental significance of microbial and chemical quality of water may have negative impacts on meat safety, water management and equipment operation and maintenance [2]. Contamination of beef carcasses may occur during various slaughter operations' including carcass washing [3,4].

As of 2018, Kajiado County had not carried out a county-led water monitoring program to assess the water quality of its surface, ground waters, nor of the water provided by subsidiary companies [5], a situation which allows instances of potentially severe microbial and chemical contamination to go unnoticed. With nearly 20 registered slaughter facilities across the county, the lack of reliable portable water for slaughter operations is a worrying concern. Water is a key component in slaughter and meat processing and a deep understanding is required to fully appreciate how it affects meat hygiene and safety. Therefore, analysis of slaughterhouse water would enhance comprehension of the role water plays in beef hygiene.

Based on comprehensive literature review, this study addresses the unexplored area concerning the quality of slaughterhouse tap water used for carcass washing in Kenya. The research findings to date have been concerned with quality of slaughterhouse wastewater and its impact on the environment [6,7,8,9]. Therefore, for sufficient control and assurance of hygienic and safe meat, control of public health hazards should get urgent priority.

The research question the study asked was, "What effect does the slaughterhouse carcass washing water have on the microbial quality of beef carcasses?" The objective of this study was, therefore, to determine the bacteriological and chemical quality of tap water used for carcass washing and sanitation operations across 5 Kajiado slaughterhouses.

MATERIALS AND METHODS

Study Area

Kajiado County (Figure 1) is located in the southern part of Kenya, in the arid and semi-arid zones. It has a population of 1.1 million people, 38 slaughterhouses and serves as an extension of Nairobi metropolis. Kajiado slaughterhouses supply red meat well beyond the county to the capital Nairobi and its environs. The county receives an average annual rainfall of about 400 mm/year [5,10]. The main sources of water include seasonal rivers, shallow wells, springs, dams, water pans and

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boreholes. Several local government subsidiary companies provide water and sewerage services in the county; however, their services have not been streamlined to guarantee sustainable management of water and sanitation for the population. Its underdeveloped water supply systems contribute to frequent acute shortage of portable water for drinking and other functional uses, leaving only 36 % of the population having access to portable piped water [5].

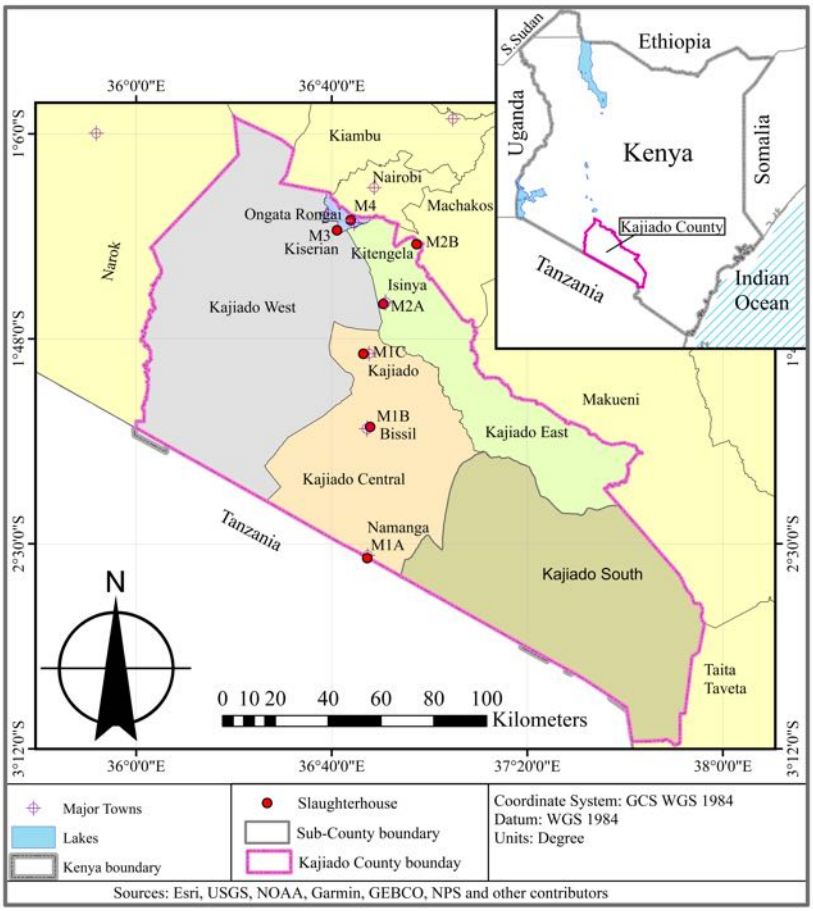

Figure 1: Map of Kajiado County, towns and study sites

Data collection tool

The data collection process was as previously described by Kimindu *et al.* [11]. Interviews in English with the slaughterhouse managers were used to gather data. Annex 1 illustrates how the questionnaire for managers was divided into five sections. The first section gathered personal data, the second section gathered information on managers' training in sanitation and meat safety, the third section examined slaughter operations, the fourth section investigated personal hygiene, and the last section examined water and waste management.

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Water sample collection

Water sampling was limited to the dry season, in November 2021, after experiencing several failed rainy seasons. For water bacteriological analysis, glass sampling bottles were cleaned, sterilized and 0.1 mL of 3 % sodium thiosulphate solution added to dechlorinate any likely residual chlorine in the sample water bottle [12]. Cattle-slaughtering facilities were purposively chosen for their closeness to the Namanga-Bissil-Kajiado-Isinya-Kiserian trade route, where five SMS in Namanga town (M1A), Bissil (M1B), Kajiado town (M1C), Isinya (M2A) and Kiserian (M3), represented slaughterhouses in this trade route.

Two 500 mL of tap water samples were collected from the five slaughter house, one for bacteriological and the other for chemical analysis. All the taps were located inside the slaughtering hall and were utilized in all sanitation activities as well as carcass washing. Out of the 5 slaughterhouse taps, only one was metallic without any piping joined to it. This tap was sterilized with a gas burner and the tap was opened and let to flow for a minute after which the water sample was collected. The other taps were connected to a plastic piping and had water flowing continuously into a collecting tank. The samples were stored in a cool box and chilled with ice packs and transported to the laboratory within 3 hours.

All aspects of research ethics were observed and the study was permitted by the National Commission for Science, Technology and Innovation (NACOSTI) (license number 738580), along with authority from the Department of Veterinary Services, Kajiado County.

Bacteriological Analyses

Determination of total coliforms

Multiple tube fermentation (MTF) technique was used for the presumptive determination of total coliforms [13]. MacConkey Broth Purple (MAC) media (Himedia, India) was prepared according to the manufacturer's procedure. Each water sample was divided into fifteen aliquots, with 5 aliquots each of 10 mL being used as inoculum into tubes of 5 mL double strength MAC, while the other 5 aliquots each of 1mL and 0.1 mL inoculated into 10 mL single strength of MAC. The tubes were incubated at 37 ± 0.5 °C for 48 hours after which the tubes are examined for gas production. By principle, coliforms ferment lactose to produce gas and acid within 48 h at 37°C. After 24 hrs, tubes with no gas production were incubated further for another 24hrs and examined. Gas production at any time within 48 hrs is a positive coliform test. The results of the replicate (5 x 3) tubes and dilutions are statistically reported as the Most Probable Number (MPN), referenced from an MPN table. The MPN is an estimate of the mean density of coliforms present in the sample, according to the method described by ISO 9308-2:2012 [14]. One loopful

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from each of the MAC tubes was streaked onto Typtone Soy Agar (TSA) and incubated at 37 °C for 48 hours.

Determination of faecal coliforms

Faecal coliforms were determined by the differential coliform (Eijkman) test, by adding a loopful of the positively-turned MacConkey Broth tubes into MacConkey Broth purple (Himedia, India) with Durham tubes and incubated at 44.5 °C ± 0.25 °C for 24 hours in screw- capped tubes [13].

***Escherichia coli* isolation**

All samples from the previous coliform test that had been streaked on TSA medium (Oxoid, UK) and incubated for 48 hours at 37 ± 0.5 °C, were streaked onto Eosin Methylene Blue (EMB) agar (Oxoid, UK) and incubated for 24 hours at 37 ± 0.5 °C for the isolation of *E. coli.*

Presumptive test for *Salmonella* and *Shigella* species

The method recommended by Getamesay and workers was used to isolate and identify *Salmonella* and *Shigella* spp. in water samples [15]. A 100 mL volume of sampled water was poured into a centrifuge filtration unit and filtered with a cellulose acetate filter with a pore size of 0.45 µm (Sartorius Stedim, Germany). The filter paper was then placed into tubes of 9 mL of tetrathionate broth (Biotec Laboratories, UK), a *Salmonella* enrichment media containing 20 % (200 µl) Iodine. The tubes were incubated at 37 °C for 24 hours. Following incubation, a loopful of the enriched mixture was streaked onto Xylose Lysine Deoxycholate (XLD) agar (Oxoid, UK) and incubated for 24 hours at 37 °C. Presumptive *Salmonella* and *Shigella* colonies were sub-cultured from XLD to nutrient agar (Oxoid, UK) plates for 24 h at 37°C to obtain pure cultures. The following biochemical tests were performed.

Determination of sugar fermentation

Triple sugar iron (TSI) test determines the fermentation of glucose, sucrose and lactose and production of gas and H_2S by Gram-negative bacteria. Triple Sugar Iron broth media (Oxoid, UK) contains glucose, sucrose and lactose in the ratio 1:10:10, peptone, tryptone, ferrous sulphate, sodium thiosulphate, and phenol red indicator among other constituents. Triple Sugar Iron broth was prepared in a slant. Inoculation was done by using a thin sterile needle and stabbing the butt and streaking the slant's surface. The tube caps were loosely capped before incubating at 37 °C for 24 hours. As interpreted by the manufacturer, when glucose is the only sugar fermented, a small amount of acid is produced turning the butt yellow (acidic) and leaving the slant red, as is typical of *Shigella* species. Similarly, *Salmonella* species only ferment glucose but not lactose or sucrose. However, its characteristic production of H_2S will be indicated by the black pigmentation of ferrous sulphide. The production of H_2S may be significant enough to cause bubbles or cracking of

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the media. When lactose or sucrose, or both sugars are fermented, a significant amount of acid is produced, turning both the butt and the slant yellow. This may be accompanied by the production of a significant amount of gas that may create bubbles or form cracks in the semi-solid media, as is characteristic of *Escherichia coli.* When no carbohydrate is fermented, the butt and slant will remain. However, when ammonia is produced by the oxidative deamination of amino acids (from peptone and tryptones), the slant can turn into a deep red or almost purple colour due to increase alkalinity as is characteristic of *Pseudomonas aeruginosa.*

Determination of urease

Urease test checks for the urease enzyme in Gram-negative bacteria, which converts urea into ammonia (NH_3) and raises the pH of urea agar (ThermoFisher, UK). This agar contains 2% urea together with the pH colour indicator, phenol red. A pH increase as a result of ammonia production causes a color change from yellow to bright pink, and is interpreted as positive test, while no colouration is negative [16]. A loopful of presumptive colonies were inoculated onto the agar and incubated at 37 °C for up to 4 days.

Determination of motility, indole production, and ornithine decarboxylase activity

Motility indole ornithine (MIO) is a qualitative test that identifies and differentiates among Gram-negative enteric *Enterobacteriaceae* based on motility, indole production and ornithine decarboxylase activity. Motility indole ornithine media (Sigma Aldrich, Germany) was prepared in a test tube and inoculated with presumptive isolates by making a single stabbing into the agar and stopping 1 cm from the bottom of the test-tube. The tubes were incubated at 37 °C for 24 hours. Prior to evaluating indole synthesis, motility and ornithine decarboxylation reactions were read. Non-motile organisms develop along the inoculation line, while motile organisms display either dispersed growth or turbidity extending out from the inoculation line. Glucose fermenters produce acid which turns the pH indicator's bromocresol purple colour yellow. Ornithine decarboxylase-containing organisms convert ornithine to putrescine, an alkaline product that raises the pH and turns it purple. Tryptophan, which is present in casein enzymic hydrolysate, is converted to indole [17].

Chemical analyses

Five 500 mL bottles were washed and rinsed with deionized water and dried ahead of sampling. Onsite, a portable multiparameter meter, HI 9813-5 (Hanna Instruments, Romania) was used to measure water pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature (manufacturer's instructions). Water samples were held in a 50 mL beaker, meter probe was inserted, and the appropriate parameter button pressed for the value to be displayed on the Light Emitting Diode

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(LED) screen. The samples were stored in a cool box and transported to the laboratory within 4 hours.

Turbidity

Turbidity was determined by the Spectronic 1001 Spectrophotometer (Milton Roy Company, USA), with a wavelength accuracy of < 1.0 nm. Distilled water was added into a cuvette and placed into the cuvette holder. At 882 nm, distilled water obtained an absorbance reading of 100. Each water sample was then placed in the cuvettes and their readings were obtained. Turbidity was then calculated by subtracting the sample readings from that of the distilled water (100) and reported in nephlometric turbidity units (NTU).

Fluoride, Nitrate and Nitrite

Sampled water fluoride and nitrite (NO_2) were determined by the DR359Tx Ion Concentration meter (EDT Instruments, UK). Each test had its unique electrode. Three standards of fluoride, 0.1, 1 and 10 ppm were prepared for device calibration. The unique fluoride electrode was immersed into the first standard until a reading was displayed and adjusted accordingly. This was repeated for the next two standards after which the electrode was immersed into the water sample and the displayed results were recorded. This procedure was repeated for nitrate and nitrite with similar standard concentrations for calibration.

Total Iron and Aluminium

The 210 VGP Atomic Absorption Spectrophotometer (Buck Scientific, USA) was used to measure elemental content of the water samples. For iron (Fe) determination, a Fe hollow cathode lamp was inserted into the light source component of the device. Air/acetylene flame was selected at a wavelength of 248.3 nm. Distilled water was used as a blank. The device was then calibrated with 3 iron concentration values of 5, 10 and 20 ppm. The water sample was then aspirated into the ionization chamber, after which the photomultiplier tube detector transmitted the absorbance results onto the readout screen. For aluminium (Al) determination, the same procedure was followed with Al standards of 5, 10 and 20 ppm. However, the flame was changed to nitrous oxide/acetylene and at a wavelength of 309.3 nm.

Ammonia

Ammonia was determined as ammonical nitrogen (NH_3-N) in a Vapodest 30s Kjeldahl distillation system (Gerhardt GmbH, Germay) [18]. Ten millilitres of the water sample was placed in a distillation tube with 5 gm of Magnesium oxide (MgO) and run for 90 seconds. Afterwards, 5 mL Boric acid was added into a conical flask together with 3 gm of methyl red indicator, and further run for 90 seconds. At this point, the flask may have turned from red to either colourless or green. The distillate was titrated back to a red end point with 0.01 N H_2SO_4. Similarly, a blank reagent

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(distilled water) was distilled, and titrated and its titre value subtracted from the titre of the water sample to arrive at the content of NH_3–N in the samples.

RESULTS AND DISCUSSION

The bacterial presumptive results are summarised in Table 1. One (20 %) borehole sample (M1B) met WHO guidelines for total coliform, scoring an MPN index of < 2, while four samples (80 %) tested positive with indices of 17, 130, 1609 and >1609 per 100 mL water sampled, corresponding to M1A, M3, M2A and M1C, respectively. The faecal coliform test revealed negative results for all samples as no colour change nor gas production was observed in the Durham tubes. However, 60 % of the samples (3/5), that is M1A, M1B and M2A tested positive for *E. coli*. Contrary to expectations, the water samples tested negative for faecal coliforms but positive for *E. coli*. These somewhat surprising results suggest that the samples may have had negligible faecal coliform counts quantitatively, but upon further growth on TSA led to an increase in their detectable numbers. In support of this finding, a previous study reported that some *E. coli* O157:H7 strains would not produce gas and turbidity at 44.5 °C if initial count was below log 2 CFU/mL [19]. This is a rather significant result, suggesting the multiple tube fermentation technique may lead to underestimates of enteric coliforms such as *E. coli* when present in low counts, since a confirmation test is only performed on tubes that exhibit a positive presumptive reaction [13].

Presumed *Salmonella* species were detected in 20 % (1/5) of the water samples, at M1A, having isolated both red and yellow colonies with black centres on XLD. The XLD manufacturer's guideline reported that *Salmonella* colonies were typically red with black centres. These results agree with the findings of other studies. Public Health England [20] reported that *Salmonella* species producing little or no hydrogen sulphide such as *Salmonella* ser. Typhi, *Salmonella* ser. Senftenberg and *S. pullorum* grow as red colonies with or lacking black centres. On the other hand, strains that do not decarboxylate lysine such as *S. paratyphi* may appear as yellow colonies with a black centre [21]. Upon confirmation on TSI (Table 2), the isolates had a red slant colour (no colour change), yellow butt (acidic) with significant production of H_2S (black precipitate) and a gas (cracked medium). The colonies further tested urease negative, indole positive, ornithine decarboxylase negative and was motile. These results are characteristic of *Salmonella* species.

Presumed *Shigella* species were detected in 60 % (3/5) of the samples (M1C, M2A and M3), with colonies on XLD appearing red without black centres. On TSI, each sample had deep red (alkaline) slant and butt and no gas nor H_2S production. The colonies were negative for urease, indole, ornithine decarboxylase and were non-motile (Table 2), typical results for *Pseudomonas aeruginosa.* To date, no evidence suggests that potable water sources contaminated with *P. aeruginosa* could be a

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source of infection in the general population. However, *P. aeruginosa* is a significant opportunistic pathogen to immunocompromised persons in hospital settings [22].

Borehole (M1B) water sample with presumed *E. coli* colonies had yellow (acidic) slant and butt and produced a significant amount of gas to raise the medium from the bottom of the tube (Table 2). The colonies did not produce H_2S, were urease negative, indole positive, ornithine decarboxylase positive and were motile. These results are characteristic of *E. coli* strains. Contamination of slaughterhouse tap water with *E. coli*, especially pathogenic strains could make the water a source of carcass contamination and thus pose public health risk to meat consumers.

An earlier survey of meat inspectors and slaughterhouse managers from the five SMS reported to be supplied with water from private suppliers of borehole and spring water and did not have direct control over the quality of water at source nor over the treatment methods utilized. Only one manager (M3), declared that chlorination was the water treatment method utilized in their facility. Three declared that the water sources were treated but did not know the method, while one did not know the status of water treatment. The results of this study are in agreement with an earlier study [2], which reported that water quality is frequently ignored in many food production and processing procedures. A study of meat and water quality across 18 South African poultry, pig and ruminant slaughterhouses reported that over 91 % of water samples tested positive for *E. coli*, contravening Government regulations [4]. Similarly, an earlier study at a pig slaughterhouse in Indonesia reported that 33.3 % (n= 6) of its reservoir water tested positive for *E. coli* O157:H7 [23]. Although the residual chlorine of M3 water sample was not determined at source, the considerably high MPN index was indicative of water contamination or inadequate chlorination.

Water chemical quality results are summarised in Table 3. The water samples appeared colourless, odourless and had no visible floating, suspended solids or sediments, implying good physical quality. Tap water temperatures ranged from 23.4 to 26.1 ℃ with a mean of 24.7 ℃, exceeding the WHO maximum water temperature of 15 ℃. Previous studies have implicated temperature to have the biggest impact on a network's water microbiological stability. Higher water temperatures are reported to stimulate the growth of microorganisms [24], and increase solubility of toxic chemicals [25,26] and influences the breakdown of residual chlorine [34]. As observed during the study, this may be partly explained by the exposure to direct sunlight of the overhead water storage tanks, which could warm the water during storage. Increase in tap water temperature has been attributed to numerous factors including the prevailing weather, presence or absence of shade, installation depth of distribution pipes, type of soil and soil temperature, groundwater levels, the presence of anthropogenic (subsurface) heat sources, and hydraulic residence times [26], [27,28].

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Water pH is one of the most crucial operational water quality parameters affecting the corrosivity of piping and sanitation. Water pH below 7 is more likely to be corrosive and should ideally be lower than 8 to effectively disinfect with chlorine since more hypochlorous ions form at lower pH, increasing the antibacterial activity [2,29,30]. Samples had a pH range of 7.7 to 8.4 with a mean of 8, which is slightly alkaline, falling within the national and WHO pH guideline range of 6.5 to 8.5.

Electrical conductivity ranged from 683 to 2533 µS/cm with a mean conductivity of 1568 µS/cm (Table 3). Four samples were within the guideline limit of 2500 µS/cm, except for M1C which had 2533 µS/cm. Total dissolved solids (TDS) ranged from 343 to 1260 ppm with a mean of 792.6 ppm. Similarly, M1C exceeded the global TDS limit of 1000 ppm, attaining 1260 ppm. Iron content ranged from 0.02 to 0.35 ppm with a mean of 0.17 ppm. The M1C and M3 samples exceeded the guideline limit of 0.2 ppm, having attained 0.24 and 0.35 ppm, respectively. Presence of iron in portable water has been attributed to the corrosivity of cast and steel iron pipes, as well as the utilization of iron-based water coagulants that may result in film production and water staining [2,31]. A technical status report on water systems in Kajiado county, reported that old and rusted metallic piping was part of the distribution infrastructure [32]. In previous studies, old metallic water pipes that are susceptible to corrosion have been linked to an increase in the probability of chemical releases into water and, consequently increasing electrical conductivity [25]. High TDS concentrations have been reported to cause severe scaling in water heating equipment. Similarly, TDS has an impact on how palatable water is, with levels < 600 ppm being ideal while unpalatability rises as TDS levels rise above 1000 ppm [31].

Turbidity measures physical impurities in water that can diminish clarity to light transmission. Particles in suspension may harbour bacteria and protect them from disinfecting agents like UV light [31]. In this study, turbidity ranged from 1.1 to 2.11 NTU with a mean of 1.75 NTU and all samples were within the WHO guideline limits of 5 NTU. Water of turbidity levels greater than 4.0 NTU appear milky, reddish-brown, or even blackish and is considered unacceptable quality for drinking [31].

Fluoride is commonly found in groundwater and may reach levels to the tune of 10 ppm. Levels higher than 1.5 ppm, however, are associated with dental fluorosis and much higher levels of 3 to 6 ppm resulting in skeletal fluorosis [31]. In the current study, fluoride content ranged from 0.72 to 2.05 ppm with a mean of 1.26 ppm. M2A sample exceeded the guideline limit of 1.5 ppm, having 2.05 ppm. An earlier study in Kenya revealed a positive relationship between the depth of underground water sources and fluoride concentrations, where an increase in depth led to an increase in fluoride concentrations up to 1 to 5 ppm [33].

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Aluminium contents of the water samples were greatly below the WHO guideline limit of 0.2 ppm [31], only being detected in sample M1A (0.027 ppm) and M2A (0.059 ppm). Like iron salts, aluminium salts are employed as water coagulants [31]. The low to undetectable quantities of aluminium indicate that they might not be used in the water treatment process in Kajiado.

Groundwater naturally contains ammonia, usually at concentrations below 0.2 ppm [29]. Ammoniacal nitrogen was not detected at M1B and M3 but was present in amounts of 0.35 ppm (M1C), 0.49 ppm (M2A) and 0.72 (M1A). Borehole water (M2A) and M1A samples bordered and exceeded the guideline limit of 0.5 ppm [31], respectively. Ammonia is however a significant part of mammalian metabolism, and its presence in the borehole and spring water samples was suggestive of contamination by either bacteria, human or animal waste.

Nitrate content ranged from 0.42 to 2.24 ppm with a mean of 1.34 ppm, all samples being below the guideline limit of 10 ppm. Nitrites were not detected. Generally, nitrites may be formed in water pipes by *Nitrosomonas spp.* when poorly oxygenated nitrate-rich water is stagnated in galvanized steel pipes, or when chloramines are utilized as a residual disinfectant [31].

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The current study shows that slaughterhouses' tap water from M1A, M1B and M2A was contaminated with *E. coli* while M1A water further had *Salmonella* spp. and exceeded in ammoniacal-nitrogen, all of which imply faecal contamination. This poses as a source of carcass contamination with potential pathogens during washing. Furthermore, tap water from M1C and M3 exceeded in Fe limits, implying possible corrosion of pipes. The water fluoride levels in M2A exceed the global limit and alludes to possible dental fluorosis of the workers and neighbouring population that drinks that water.

This study recommends the urgent sensitization of slaughterhouse management and local authorities on the critical role water quality plays in carcass hygiene, sanitation operations and human health. Secondly, the slaughterhouse management and local authority should reinforce the microbial and chemical quality of their water by putting in place sustainable water treatment and monitoring plans to avail portable water for carcass washing, slaughterhouse sanitation and ensure worker health. Similarly, the study recommends replacing the water piping system from metallic to plastic, in order to reduce corrosion, to lower EC and TDS of the water. All these recommendations will mitigate the transmission of both present and emerging water-borne hazards and enhance sanitation operations.

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A critical limitation to this study was the sampling season solely representing dry season data, and with the impact of seasons on water quality previously demonstrated, it would be paramount to determine the contamination risks of water quality between wet and dry seasons. Further studies regarding the role of water temperature and residual chlorination on bacteriological water quality would be worthwhile. Similarly, the question raised by the coliform detection method used in this study, requires more research for a more sensitive and reliable method.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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Table 1: Presumptive Results for Total and Faecal coliform, *Escherichia coli*, *Salmonella* and *Shigella*

SMS	Water source	Coliform (MPN/100 mL)	Faecal coliform (MAC)	*E. coli* (EMB)	*Salmonella* (XLD)	*Shigellal* Pseudomonas (XLD)
M1A	Spring	17	-	+	+	-
M1B	Borehole	<2	-	+	-	-
M1C	Borehole	> 1609	-	-	_	+
M2A	Borehole	1609	-	+	_	+
M3	Borehole	130	-	-	_	+

MPN = Most Probable Number; MAC = MacConkey Broth, EMB = Eosin Methylene Blue, XLD = Xylose Lysine Desoxycholate media

Table 2: Confirmatory Results for Biochemical Tests

Biochemical tests	M1A	M1B	M1C	M2A	M3
TSI: slant / butt	NCC/A	A/A	K/K	K/K	K/K
TSI: H_2S production	H_2S	-ve	-ve	-ve	-ve
TSI: gas production	+ve	+ve	-ve	-ve	-ve
Urea	-ve	-ve	-ve	-ve	-ve
MIO: motility	+ve	+ve	-ve	-ve	-ve
MIO: Indole	+ve	+ve	-ve	-ve	-ve
MIO: Ornithine	-ve	+ve	-ve	-ve	-ve
Identification	*Salmonella*	*E. coli*	*P. aeruginosa*	*P. aeruginosa*	*P. aeruginosa*

KEY: TSI = triple sugar iron test, H_2S = hydrogen sulphide production, MIO = motility, indole ornithine test, NCC = No colour change, K = alkaline, A = acid, -ve = negative result, +ve = positive result, Salmo. = *Salmonella* species, P. aero = *Pseudomonas aeruginosa*

Table 3: Results for Water Chemical Quality

Sample	Water source	Water pH	Water Temp (°C)	Ec (µS/cm)	TDS (ppm)	T (NTU)	F (ppm)	Fe (ppm)	Al (ppm)	NH_3-N (ppm)	NO_3-N (ppm)
M1A	Spring	7.7	23.7	820	428	1.65	0.72	0.12	0.027	0.72	1.12
M1B	Borehole	7.7	25.7	1884	953	1.1	0.78	0.02	ND	ND	0.42
M1C	Borehole	7.9	24.5	2533	1260	2.11	1.33	0.24	ND	0.35	2.24
M2A	Borehole	8.4	23.4	1920	979	2.1	2.05	0.11	0.059	0.49	1.40
M3	Borehole	8.3	26.1	683	343	1.8	1.4	0.35	ND	ND	1.54
WHO max. limits		6.5-8.5	15	2500	1000	5	1.5	0.2	0.2	0.50	10.0

KEY: WHO = World Health Organization, Ec = Electrical conductivity, T = turbidity, NTU = nephlometric turbidity units, F = fluoride, Fe = Iron, Al = aluminium, NH_3-N = ammonium, NO_3-N = nitrate, NO_2-N = nitrite, TDS = total dissolved solids

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Annex 1: QUESTIONNAIRE FOR THE SLAUGHTERHOUSE MANAGER

Slaughterhouse name:

Location:

Questionnaire no:

Interview date:

SECTION 1: PERSONAL INFORMATION						
	Interviewee Name					
1	**Age (years)**					
2	**Sex**	Male		Female		
3	**Religion**	Christian	Muslim		Other	
4	**Education level**	Secondary	College	Undergraduate	Graduate	
5	**Employment type**	Permanent		Contract		
6	**Work experience (years)**					
SECTION 2: SANITATION AND MEAT SAFETY TRAINING						
7	**Have you received sanitation and meat safety training?**	Yes		No (proceed to Q.8)		
7.1	**If yes, latest date**					
7.2	**How long was the training?**					
7.3	**Topic(s) of training:**	…… …….. ……				

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		…… …… ……	
7.4	**Training Institution /Authority**		
8	**Is hygiene and meat safety training offered to slaughterhouse workers?**	Yes	No (Proceed to Q.9)
8.1	**What categories of slaughterhouse workers are offered training? (tick accordingly)**	i. All workers ii. Stunner iii. Splitter	iv. Eviscerator v. Washer vi. Dispatcher
8.2	**How often is the training offered?**		

SECTION 3: SLAUGHTER OPERATIONS

9	**Which animals are slaughtered?**	Cattle only	Cattle and shoats	Cattle calves and shoats			
		Cattle and calves					
10	**What is the max. slaughtering capacity in a day?**						
11	**What is the cost of slaughtering cattle, sheep and goat?**	Cattle KSh.	Sheep KSh.	Goats KSh.			
12	**Has the price of 1 kg of beef changed in the past 5 years? (Refer to records)**	Year	2017	2018	2019	2020	2021
		Price/ kg					
13	**What is the mode of payment**	Cash	Credit	Cash and Credit			
14	**What was the number of cattle slaughtered last year? (Refer to records)**	2016	2017	2018	2019	2020	

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15	**What is the average live weight of cattle slaughtered? (Kg)**				
16	**What is the average carcass weight of cattle?**				
17	**What is the condition of the cattle hides**	very dirty	dirty	clean	
18	**Are the cattle cleaned in any way ahead of slaughter?**	No	By scrapping	By washing with water	other
19	**What is the slaughtering operation practiced**	Ritual slaughter (halal) -no stunning		Stunning with ritual slaughter (halal)	
19.1	**If stunning is done, which stunning method is used?**				
20	**Does the slaughterhouse store carcasses under refrigeration?**	Yes	Sometimes (explain)	No (Proceed to Q 21)	
20.1	**If yes, what equipment are available?**	Ice supply	Refrigerators	Freezers	Cold room
21	**Where is the end-market?**	sub-county	other sub-counties	Other distant towns	
22	**Do you have ready market the following cattle products?**				
	Hides	price/ kg			
	Head	price/pc			
	Blood	price/ltr			
	Horns and bones	price/kgs			
	Fat	price/kg			
	Other slaughter by-products				

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SECTION 4: PERSONNEL HYGIENE AND SANITATION						
23	**Type of protective clothing worn: (tick appropriately)**	Overalls	Apron	Lab coat	Gloves	Cap or hairnet
24	**Who provides this clothing?**					
25	**Where is this clothing cleaned?**	Slaughterhouse		workers home		
26	**Who provides the footwear?**	Slaughterhouse management		Workers		
27	**Are hand washing sinks available in the slaughtering hall**	Yes		No (Proceed to Q 28)		
27.1	**If yes, where are they located**	At the entry to the hall	Inside the hall	Outside the hall		
27.2	**Is soap provided?**	Yes		No		
28	**What type of toilet facilities are provided?**	Pit latrines		Flushable toilets		
29	**Are hand washing sinks provided at the toilet facilities?**	Yes		No		
30	**Are changing rooms provided?**	Yes		No		
31	**Is a meal / lunch area provided**	Yes		No		
SECTION 5: WASTE MANAGEMENT						
32	**List types of wastes generated from slaughter operations**	i. ii. iii.		iv. v. vi.		
33	**What disposal method is employed for slaughter waste?**	Burning	Burying in a pit	Thrown for collection	Feeding scavengers	Taken home by workers	Selling to public

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34	**Where do you obtain your water for slaughtering?**	Borehole	River	Tap	Well	Rain
35	**Is the water treated?**	Yes		No		
35.1	**If yes, by which method?**	Chlorination	Reverse osmosis	Filtration	Demineralization	
		Ozonation		Other		

THANK YOU FOR YOUR PARTICIPATION

We would not have come this far without you !!