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Research Article

Relationship between Water Quality Parameters and Parasite Infestation in Farmed *Oreochromis niloticus* in Selected Rift Valley Counties, Kenya

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Globally, parasitic infections hinder aquaculture productivity and sustainability. Improper water quality parameters reduce fish immunity, make them susceptible to parasites, and enhance parasitic proliferation in culture systems. Subsequently, this study aimed to determine the prevalence and intensity of ecto- and endo-parasite infesting *Oreochromis niloticus* in varying water quality in aquaculture systems in Kericho, Bomet, and Nakuru counties. A total of 220 *Oreochromis niloticus* samples were captured from 11 liner ponds, eight earthen ponds, two concrete ponds, and one plastic tank from 22 farms in the three counties. External and internal organs were examined for parasite infestation. Skin scrapings and squash preparation of fish eyes were also examined to reveal the organisms through microscopic examination. A Pearson's correlation analysis between physicochemical parameters and parasitic prevalence was used to determine the strength and direction of correlation coefficients with significance at 95%. Overall parasitic prevalence infestation was 39.6% (87/220). Ten parasite genera were recovered, with *Dactylogyrus* species dominating overall at 15.9% (35/220), followed by *Trichodina* spp. (7.7%; 17/220). *Epistylis* species had the highest mean intensity of 12.8 ± 35.7 (total number of *Epistylis* parasites (141)/total of infested fish (11)). Earthen ponds had a significantly higher (36.2%, 29/80) prevalence of *Dactylogyrus* sp. than liner ponds (3.6%, 4/110) ($p < 0.001$). Dissolved oxygen levels were 16.9 ± 0.7 mgL^{-1} in Bomet, 14.9 ± 0.3 mgL^{-1} in Kericho, and 12.5 ± 0.5 mgL^{-1} in Nakuru which were above desirable range for fish culture. The electrical conductivity in Bomet was $76 \pm 5\,\mu$S/cm and Kericho $52 \pm 4\,\mu$S/cm below the desirable range. Temperature, pH, phosphate, nitrates, and nitrites were within the desirable limit for fish farming. Electrical conductivity and pH had positive correlation of 1 and 0.97, respectively, with the prevalence of *Acanthocephalus*, *Euclinostomum*, and *Trichodina* species. Temperature and nitrate positively correlated between 0.80–0.89 and 0.90–0.99, respectively, with the prevalence of *Dactylogyrus*, *Riboscyphidia*, *Epistylis*, *Camallanus*, and *Paracamallanus* species. The study demonstrates that water quality significantly influences parasitic prevalence in aquaculture systems. Therefore, it is crucial for farmers to monitor water quality parameters to mitigate parasitic infestations.

1. Introduction

The global increase in human population is exerting pressure on capture fisheries, resulting in excessive fishing and a subsequent decrease in the wild fish population [1]. To address the need for sustainable seafood for consumption, there has been a surge in the aquaculture food sector worldwide [2]. More than 800 million people are involved in fisheries and aquaculture economic activities [1]. Overall, more than three million individuals from less advanced and developing nations experiencing poverty have access to protein and high-quality polyunsaturated fatty acids in their diet obtained from fish [1]. Aquaculture has played a major role in supporting food security for poor people and reducing malnutrition [3]. Globally, aquaculture produces 80 million tonnes, with Africa accounting for only 2.7% [1, 2]. In Kenya, fisheries production as of 2020 was 147,000 MT with a value of $237 million. Inland production contributed 120,000 MT, of which 18,542 MT was from aquaculture [4]. With government support, scientific research, and many innovations in fish farming, farmers were encouraged to invest in aquaculture. However, there are several challenges, such as poor genetic material, cost of feeds, lack of markets, predation, and diseases [5, 6, 7, 8].

Most farmers have little or no knowledge on fish health and farm biosecurity in Kenya [6]. Studies done in different parts of Kenya confirm the presence of fish pathogens [8, 9, 10]. Pathogens are ubiquitous in aquatic environment where fish are found, and the interplay between the host, pathogens, and aquatic environment leads to the development of illnesses in fish [11]. Fish immunity is affected by the condition of the aquatic habitat, which affects fish health and makes them more susceptible to disease [12].

It has been reported that parasites pose a significant barrier to the expansion of intensive fish cultivation [13, 14, 15]. Many farms have experienced economic losses due to fish losing vision, emaciation, mortality, morbidity, stunted growth, and loss of aesthetic value leading to condemnation during fish inspection due to parasitic infestations [16, 17].

Few studies have been done in Kenya determining correlation of water quality on parasitic diseases occurrence in lakes and fish farms [18, 19, 20]. This study addresses the gap in understanding the impact of water quality on the prevalence of parasitic infections in aquaculture systems. In Kericho and Bomet, no studies on fish parasites have been done. The study differs from Ojwala et al. [19] study in Nakuru where the focused was on how farm practices affect water quality and the impact of water quality in parasitic occurrence. Understanding the relationship between water quality and parasitic prevalence can help develop better management practices, reducing economic losses and improving fish health.

2. Materials and Methods

2.1. Ethical Clearance. Ethical clearance was obtained from the Biosafety, Animal Use and Ethics Committee of the Faculty of Veterinary Medicine, University of Nairobi (REF: FVM BAUEC/2023/421), and from the National Commission for Science, Technology and Innovations (Licence No. NACOSTI/P/23/30841). Verbal consent was sought from the directors of fisheries of the respective county and from the selected farmers prior to fieldwork.

2.2. Study Area. The study was undertaken in selected active fish farms in March in Bomet, April in Kericho, and July in Nakuru counties in 2023 (Figure 1). Kericho County is approximately 256 km from Nairobi and is located in the southern portion of the Great Rift Valley. The county has an elevation of approximately 2,002 m above sea level and is located between longitudes 35°02′ and 35°40′ E, as well as between the equator and latitude 0°23′ S. Bomet County lies between latitudes 0°29′ and 1°03′ S and longitudes 35°05′ and 35°35′ E. Nakuru County lies between longitude 35°28′ and 35°36′ E and Latitude 0°13′ and 1°10′ S, with an approximate land coverage area of 7,495.1 km^2 in the Great Rift Valley region in Kenya, 160 km northwest of Nairobi along the Kenya–Uganda Highway.

2.3. Study Design, Sample Size Determination, and Sampling Techniques. A cross-sectional study involving collection of fish samples and measurement of physicochemical parameters of pond water was carried out during visit of selected farms in the three counties between March and July 2023. The study followed unexplained fish mortalities in Kericho County, thereby necessitating investigation in the two neighbouring counties with active fish farming. The collected fish were examined for the presence of parasites, which were then isolated and identified using morphological characteristics following standard parasitological procedures [21, 22, 23]. Pond water quality assessment was done by analysing different physicochemical parameters according to the standard procedures [24].

The sample size of tilapia fish for parasitological examinations was calculated using the proportion formula, $n = \frac{Z^2 P(1-P)}{L^2}$, by Naing et al. [25], where n is the minimum sample size, Z is the Z-statistics for 95% confidence interval (1.96), L is the expected error of 0.05, and P is the anticipated prevalence which is 86.5%. By applying the formula, the minimum sample of fish was 185. However, this was adjusted to 220 fish (Kericho, $n = 90$; Bomet, $n = 60$; and and Nakuru, $n = 70$) in order to increase precision. Fish farm selection was on the basis availability of active fish ponds and farmer's willingness to participate in this study. Subsequently, 22 active fish farms consented to this study as follows: Kericho ($n = 9$), Nakuru (7), and Bomet (6).

Of the selected farms, 11 farms (Nakuru, $n = 5$; Kericho, $n = 4$; and Bomet, $n = 2$) had liner ponds, while eight farms (Kericho, $n = 5$, and Bomet, $n = 3$) had earthen ponds. One farm from both Bomet and Nakuru counties had concrete ponds, while another farm from Nakuru County raised fish in plastic tank. A total of 10 fish samples were collected in each pond and/or per farm. Out of 220 fish captured, 110 were from liner ponds, 80 from earthen ponds, 20 from concrete ponds, and the rest from plastic tank pond. The sampling and water quality assessment was done separately in 3 continuous days in a given month per county.

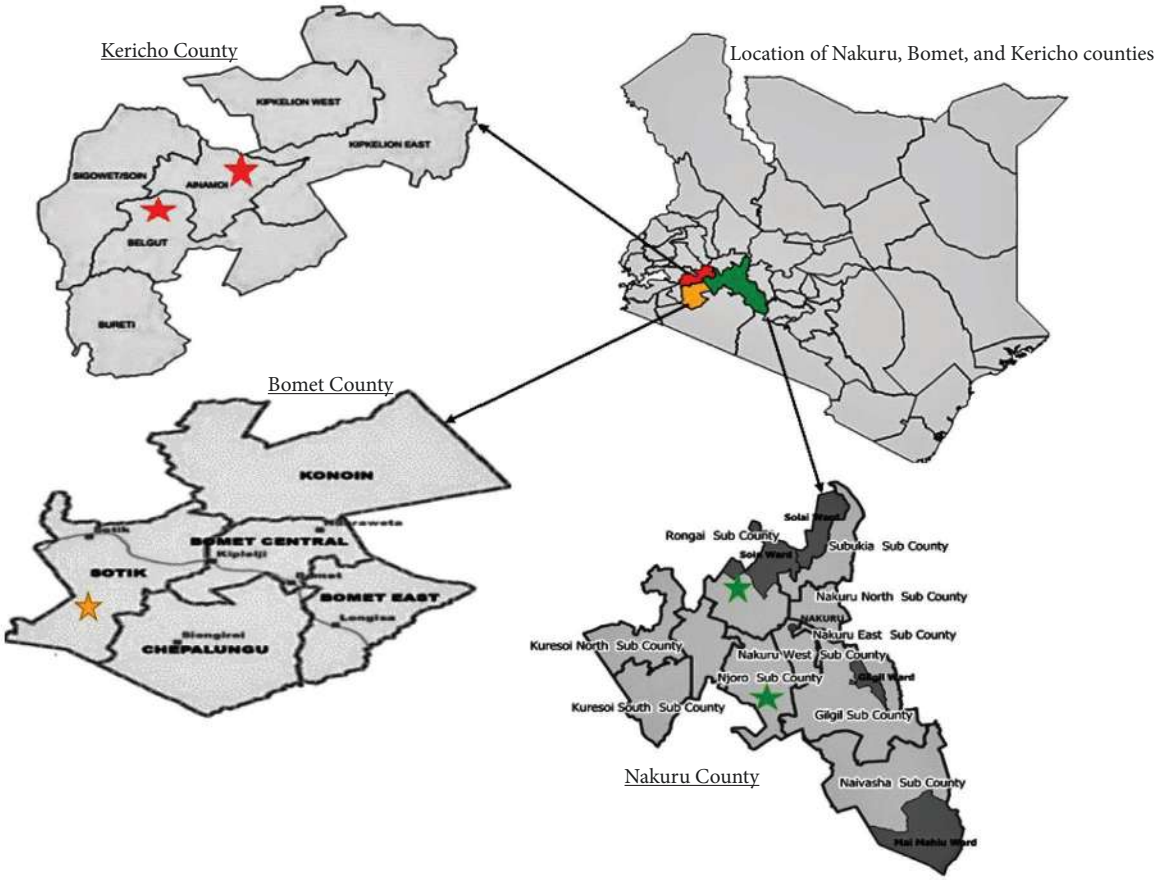

FIGURE 1: A map showing the location of Kericho, Bomet, and Nakuru counties, Kenya (shaded red, orange, and green, respectively).

2.4. Water Quality Assessment. The physicochemical parameters of water were measured in the selected study ponds in each of the recruited farms in the morning hours before 10:00 am. Water quality parameters including pH, temperature (°C), and dissolved oxygen (mgL^{-1}) were measured *in situ* using a portal waterproof HANNA Multiprobe meter (Hanna Instruments Inc., USA) prior to sampling of fish for parasitological examination. Additionally, 2 L of pond water was collected for *ex situ* chemical analysis of phosphates, nitrites, nitrates, ammonia-free nitrogen, conductivity ($\mu S/cm$), and turbidity (nephelometric turbidity units (NTUs) through spectrophotometry methods carried out at the Government Chemist Laboratories, Kenyatta National Hospital, Nairobi.

2.5. Fish Sample Collection, Necropsy, and Parasitological Examination. Two hundred twenty (220) fish samples were captured from the ponds in which water quality was assessed. They were harvested from the ponds using seine nets with the help of fish harvesters. The collected fish were immediately placed in oxygenated bags with their source pond waters and transported to the Regional Veterinary Investigation Laboratories in Kericho and Nakuru counties and to field laboratory setup in Sotik, Bomet County for necropsy and examination of ectoparasites, tissue trematodes, and gut endoparasites.

Fish were humanely euthanized by a sharp blow on the cranium and then pithed to separate the central nervous system from the spinal cord. After that, gross examination for the presence of ectoparasites and pathological lesions such as wounds/ulcers was performed. The external surface of the gills and body wall was macroscopically and microscopically examined. Freshly prepared wet mounts of skin scrapings and gill filaments on slides were examined under a microscope [22]. After that, each fish was placed on the dissecting table with its side up. In each fish, both eyes were dissected out, lens were separated from the vitreous humour, and the squash/contents were expressed on a slide for inspection of eye-dwelling flukes. A longitudinal incision was made along the ventral midline up to the operculum from a transverse incision anterior to the vent. The fish's abdominal wall was cut again from the transverse wall, this time in an arc up to the upper corner of the operculum. The two incisions were then made at the operculum to remove the muscle flap. The peritoneal cavity and the organs were separated after being thoroughly checked for parasites. The entire digestive tract was removed, and its contents were placed on a petri dish containing physiological saline (0.9% sodium chloride solution), for endoparasite recovery and identification as per the guideline by Noga [22] and Roberts [23].

Gut samples that could not be examined immediately were removed and preserved in containers with 70% alcohol, stored in cooler boxes packed with ice packs and transported to the Parasitology Laboratory of Department of Veterinary

Pathology, Microbiology and Parasitology, University of Nairobi, for parasitological analysis within 48 hr. In the laboratory, the gut was removed from 70% alcohol, placed in saline, and then divided into sections. The contents were expressed before being examined for parasites under a dissecting microscope.

2.6. Data Analysis. The frequency, average amount, and average severity of infection, as reported by Margolis et al. [26] and Bush et al. [27], were used to evaluate parasitic infections. The quantification of parasites was performed using prevalence and mean intensity formulas: $\text{Prevalence (P)} = \frac{\text{Number of fish infected with parasites}}{\text{Total number of fish examined}} \times 100$, and $\text{Mean intensity} = \frac{\text{Total count of a specific parasite}}{\text{Number of fish infected with that parasite}}$, respectively [27].

Statistical analysis was performed using R Foundation software. One-way analysis of variance (ANOVA) was used to compare the means of each physicochemical parameter from every study site. Chi-square test of association was used for comparisons of fish parasite prevalence among the counties and culture systems. A p value > 0.05 indicated lack of association. Pearson's correlation was run between each physicochemical parameter and prevalence of every parasite to determine the relationship. A positive correlation coefficient meant direct correlation or relationship which means an increase in the level of the parameter would increase the prevalence and vice versa. Correlation coefficients range between −1 and 1; therefore, a correlation close to 1 or −1 means the correlation is strong, and a correlation farther away from −1 and 1 means a weak correlation 0 means no correlation and 1 means perfect correlation with significance at 95% CI. The data regarding the sites and culture system were excluded before correlational analysis to ensure reliability and validity of correlation results.

3. Results

3.1. Nile Tilapia Parasites and Their Prevalence. The overall prevalence of parasitic infestation was 39.6% (87/220), with the infected fish samples found to be infested by one or more parasites. The prevalence of parasites in the counties differed, but the difference was not significant ($p > 0.05$). Kericho County had the highest prevalence, at 48.89% (44/90); Bomet, 33.33% (20/60); and Nakuru, 32.86% (23/70). In culture system, 52.5% (42/80), 35.45% (39/110), 30% (3/10), and 15% (3/20) of the fish from earthen ponds, liner ponds, tanks, and concrete ponds, respectively, were found to be parasitized. Ten genera of fish parasites were recovered and included ectoprotozoan *Trichodina* (7.7%), *Epistylis* (5%), and *Riboscphydia* sp. (4.5%). *Dactylogyrus* (15.9%) in the gills were the only ectoparasite monogenean recovered. Endoparasites recovered included tissue trematodes *Diplostomum* (3.6%) and *Euclinostomum* (2.3%). Nematodes were *Paracamallanus* (3.2%), *Contracaecum* (1.8%), and *Camallanus* (1.8%). The thorny head worm *Acanthocephalus* was recovered and had a prevalence of 0.9%. Individual fish genera per county are shown in Table 1. *Dactylogyrus* was recovered in the three counties at a prevalence of 28.9% in Kericho, 10% in Bomet, and 4.3% in Nakuru County, which were significantly different ($p < 0.05$). *Trichodina* was also recovered in all study counties, while the *Acanthocephalus* (2.9%) and *Euclinostomum* (7.1%) were only recovered in Nakuru County. *Dactylogyrus* prevalence was the highest in earthen ponds (36.3%) relative to concrete (20%) and liner (3.6%) ponds, and differences were significant (<0.001) (Table 1).

3.2. Necropsy and Microscopic Findings

3.2.1. Monogenean Worms. Mature *Dactylogyrus* sp. was recovered from gills of Nile tilapia. The parasite has two eyespots at the anterior end and attaches to the host's adjacent gill lamellae by a haptor with two pairs of anchors, one connecting bar, and seven pairs of marginal hooks at the posterior end.

3.2.2. Protozoan Parasites. Three protozoan parasites were found:*Trichodina*, *Epistylis*, and *Riboscyphidia* species. *Trichodina* species were recovered from skins and fins. Under the microscope, *Trichodina* parasites were observed moving freely and had cilia on the edge of the disk. They appear round with cilia and hemispherical disc shape.

Epistylis sp. and *Riboscyphidia* sp. were recovered from the skins of Nile tilapia. Under the microscope, *Epistylis* appeared as stalked zooid ciliates, with disc-shaped telotroch with cilia for locomotion.

3.2.3. Digenean Trematodes. Diplostomum sp. metacercaria were isolated actively swimming alive from the vitreous humour of *O. niloticus*. They were identified by distinct bipartite body, spatulating prosoma without ventral cavity and elongating opisthosoma (Figure 2). Oral sucker was subterminal, transversely equal.

Metacercariae of *Euclinostomum* sp. were found in the kidney as round cysts infesting the anterior and posterior parts of *O. niloticus* kidney (Figure 3).

3.2.4. Nematodes. Larvae *Contracaecum* sp. with thick cuticle were found coiled in the pericardial cavity, abdominal cavity, and gastrointestinal tract of Nile tilapia. *Contracaecum* larvae appear 20–30 mm long, transparent via greyish to brownish colour (Figure 4).

Paracamallanus sp. and *Camallanus* sp. were recovered from the gastrointestinal tract of Nile tilapia. Figure 5 illustrates the buccal capsule on the posterior of *Paracamallanus* parasite.

3.2.5. Spiny Headed Worms. Acanthocephalus sp. was recovered from the gastrointestinal tract of Nile tilapia. Identification of acanthocephalans was based on their protruding proboscis (Figure 6).

3.3. Mean Intensity of Parasites Recovered from O. niloticus. The intensities of genera infesting *O. niloticus* in the three counties are shown in Table 2. *Diplostomum* sp. overall intensity was 3.38 ± 3.16, and liner ponds had the highest intensity of 4.6 ± 3.51 of this endoparasite. County mean intensity was 4.7 ± 4.7 (Kericho) and 2.6 ± 2.1 in Nakuru County. *Dactylogyrus* sp. intensity was $3.7 \pm 2.$ in Kericho, 2.67 ± 2.1 in Nakuru, and 1.7 ± 0.8 in Bomet county and in culture systems. *Dactylogyrus* sp. intensity was the highest in earthen ponds (3.5 ± 2.56).

Table 1: Percentage prevalences of parasite genera and organ affected in *Oreochromis niloticus*, in different cultural systems and counties.

Parasite genera	Organs infected	Overall prevalence ($n = 220$)	Prevalence per county (%)			p-Value	Prevalence per culture systems (%)				p-Value
			Bomet ($n = 60$)	Kericho ($n = 90$)	Nakuru ($n = 70$)		Concrete ($n = 20$)	Earthen ($n = 80$)	Liner ($n = 110$)	Plastic tank ($n = 10$)	
Diplostomum sp.	Eyes	8 (3.6%)	—	3 (3.3%)	5 (7.1%)	0.085	—	1 (1.3%)	5 (4.6%)	2 (20%)	0.059
Acanthocephalus sp.	GIT	2 (0.9%)	—	—	2 (2.9%)	0.2	—	—	2 (1.8%)	—	0.6
Dactylogyrus sp.	Gills	35 (15.9%)	6 (10%)	26 (28.9%)	3 (4.3%)	<0.001	2 (20%)	29 (36.3%)	4 (3.6%)	—	<0.001
Euclinostomum sp.	Kidney	5 (2.2%)	—	—	5 (7.1%)	0.004	—	—	5 (4.6%)	—	0.2
Riboscyphidia sp.	Skin	10 (4.6%)	5 (8.3%)	5 (5.6%)	—	0.029	—	4 (5%)	6 (5.5%)	—	0.9
Epistylis sp.	Skin	11 (5%)	3 (5%)	8 (8.9%)	—	0.019	—	1 (1.3%)	10 (9.1%)	—	0.075
Trichodina sp.	Skin, fins	17 (7.7%)	5 (8.3%)	4 (4.4%)	8 (11.4%)	0.2	—	6 (7.5%)	11 (10%)	—	0.5
Contracaecum sp.	GIT	4 (1.8%)	—	2 (2.2%)	2 (2.9%)	0.6	—	2 (2.5%)	2 (1.8%)	—	>0.9
Paracamallanus sp.	GIT	7 (3.2%)	2 (3.3%)	5 (5.6%)	—	0.11	—	5 (6.3%)	2 (1.8%)	—	0.4
Camallanus sp.	GIT	4 (1.8%)	1 (1.7%)	2 (2.2%)	1 (1.4%)	>0.9	1 (5%)	1 (1.3%)	1 (0.9%)	1 (10%)	0.13

Key: Sp, species; GIT, gastrointestinal tract; chi-square test of association.

FIGURE 2: *Diplostomum* sp. recovered from the vitreous humour of the eyes of *O. niloticus* showing cylindrical hind body.

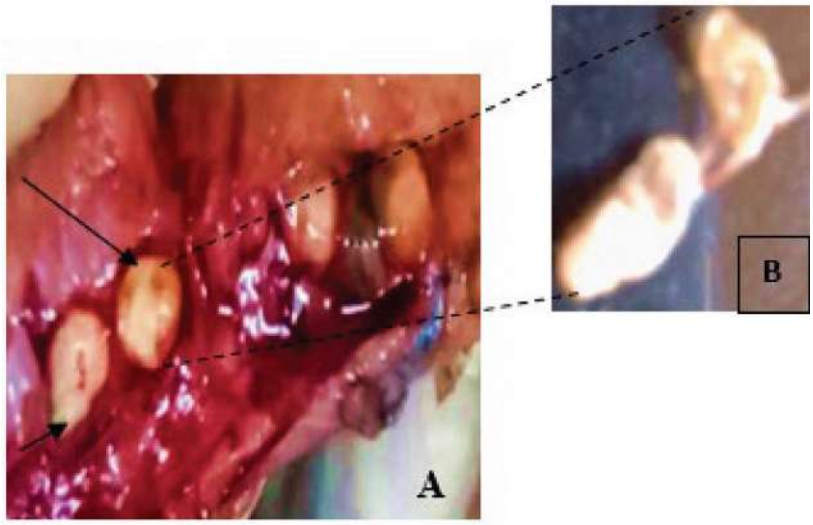

FIGURE 3: *Euclinostomum* species round nodular cysts (black arrows) encysted in congested kidney of *O. niloticus* (A). Highly active excysted metacercariae of *Euclinostomum* spp. from *O. niloticus* (B).

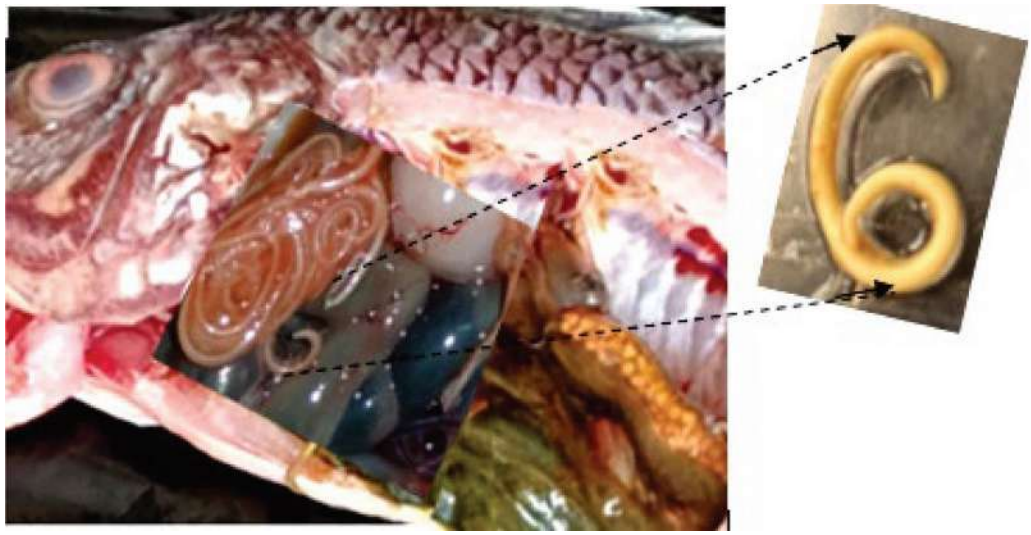

FIGURE 4: Third-stage larvae (L_3) of *Contracaecum* spp. in the pericardial cavity and abdominal cavity of Nile tilapia.

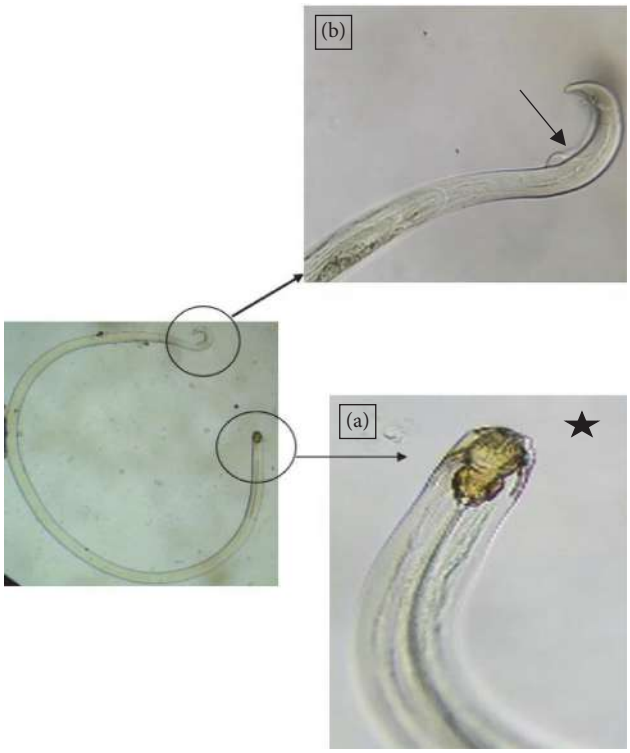

FIGURE 5: *Paracamallanus* sp. recovered from the intestines of tilapia showing anterior segment (a) bearing the buccal capsule (black star) and posterior segment (b) with the genital flap.

FIGURE 6: *Acanthocephalus* sp. showing protruding proboscis (arrow) from the gastrointestinal tract of Nile tilapia.

Euclinostomum sp. intensity was 11.2 ± 2.8 in Nakuru and in liner ponds.

Trichodina sp. intensity was 10.1 ± 16.3 in Nakuru, 2.3 ± 2.5 in Kericho, and 1.2 ± 0.5 in Bomet. The intensity of *Trichodina* sp. was high in liner (7.7 ± 14.3) compared to earthen ponds (1.8 ± 2.0).

However, all these differences were not statistically significant ($p > 0.05$).

3.4. Physicochemical Water Parameters in the Three Counties. Table 3 shows the physicochemical parameters of ponds recorded showing the mean range against desirable range for fish culture. All counties had average dissolved oxygen above the desirable range. Kericho and Bomet had electrical conductivity below the desirable range, while carbonate hardness was below the desirable range in Kericho.

3.5. Effect of Water Quality Parameters on Occurrence of Fish Parasites. A number of physicochemical parameters of pond water were found to influence parasitic infestations in the sampled fish. Sulphate concentration in pond water had positive correlation of 1 with parasites such as *Diplostomum*, *Dactylogyrus*, *Riboscyphidia*, *Epistylis*, *Trichodina*, *Contracaecum*, *Paracamallanus*, and *Camallanus* species. Temperature influenced the occurrence of *Diplostomum* (0.87), *Dactylogyrus* (0.88), *Riboscyphidia* (0.83), *Epistylis* (0.84), *Contracaecum* (0.97), *Paracamallanus* (0.80), and *Camallanus* (0.89). pH influenced the occurrence of *Diplostomum* (0.66), *Acanthocephalus* (0.97), *Euclinostomum* (0.97), and *Trichodina* (0.98). The abundance of *Acanthocephalus*, *Euclinostomum*, and *Trichodina* species had positive correlation of 1 with electrical conductivity. Nitrates were positively correlated with the occurrence of *Dactylogyrus* (0.91), *Riboscyphidia* (0.95), *Epistylis* (0.94), *Camallanus* (0.90), and *Paracamallanus* (0.96). Phosphate concentration was also positively correlated with *Dactylogyrus* (0.79), *Riboscyphidia* (0.85), *Epistylis* (0.84), *Paracamallanus* (0.87), and *Camallanus* (0.78) species. Table 4 shows the effect of water quality parameters on occurrence of fish parasites

4. Discussions

Parasites are usually ubiquitous and in dynamic equilibrium with their host(s), like other pathogens. Any alteration of the parasite/host equilibrium by any environmental or other factors can cause disease, mortality, stunted growth, and to some extent, rejection of fish and their products in the market [16, 17, 28, 29]. The overall prevalence (39.6%) of various parasites in this study was lower than the 67.8% reported by Mavuti et al. [13]., in Nyeri County, Kenya. However, the results are comparable to prevalence rate of 41% in Egypt [30] and 38.6% in Ethiopia [31]. Among the counties, Kericho County with 48.89% had the highest parasitic infections, followed by Bomet 33.33% and Nakuru County 32.86% ($P > 0.05$). The disparity in parasitic infestations may be attributed to the variable geoclimatic conditions, aquaculture husbandry and seasonality among other variables that could make fish vulnerable or resistant to parasitic infection. Kericho County has a tropical wet and dry climate, while Bomet and Nakuru are generally temperate; this coupled by differences in culture production system could explain the difference. Warm temperatures enhance the rates of egg hatching and larval development in some endoparasites. However, the high prevalence recorded in Kericho was a factor of culture production system rather than climate (as most farmers practiced earthen pond production systems which is known to predispose fish to parasite).

Among the infested fish, 10 diverse genera of parasites were recorded overall, with Kericho County having 8 of them, followed by Nakuru (7) and Bomet (6). The parasite diversity in the counties could be a result of poor aquaculture practices, as reported by Maina et al. [32] in Kiambu County and Mavuti et al. [13] in Nyeri County, Kenya. The presence of piscivorous birds (definitive hosts) around farms contaminates the ponds with eggs for parasites with indirect life

Table 2: Mean intensities of parasite genera infesting *O. niloticus* in different cultural systems and counties.

Parasite genera	Overall intensity	Intensities in counties			Intensities in culture systems			
		Bomet	Kericho	Nakuru	Plastic tanks	Concrete	Liner	Earthen
Diplostomum	3.4 ± 3.2	—	4.7 ± 4.7	2.6 ± 2.1	1.5 ± 0.71	—	4.6 ± 3.51	1
Acanthocephalus	1.0 ± 0.0	—	—	1.00 ± 0.0	—	—	1 ± 0	—
Dactylogyrus	3.3 ± 2.4	1.7 ± 0.82	3.7 ± 2.6	2.67 ± 2.1	—	3.5 ± 2.1	2 ± 1.1	3.5 ± 2.56
Euclinostomum	11.2 ± 2.8	—	—	11.2 ± 2.8	—	—	11.2 ± 2.8	—
Riboscyphidia	18.2 ± 32.3	4.0 ± 3.08	32.4 ± 42.7	—	—	—	12.3 ± 18.6	27 ± 49
Epistylis	12.8 ± 35.7	4.7 ± 6.4	15.9 ± 42.1	—	—	—	14 ± 37.4	1
Trichodina	5.6 ± 11.7	1.2 ± 0.45	2.3 ± 2.5	10.3 ± 16.3	—	—	7.73 ± 14.3	1.83 ± 2.0
Contracaecum	1.3 ± 0.5	—	1.5 ± 0.7	1.0 ± 0.0	—	—	1 ± 0	1.5 ± 0.7
Paracamallanus	10.4 ± 17.6	5.5 ± 0.7	12.4 ± 21.1	—	—	—	28 ± 31.1	3.4 ± 2.1
Camallanus	2.3 ± 1.3	2.0	2.5 ± 2.1	2.0	2.0	2.0	1.0	4.0

Table 3: Mean physicochemical water parameters in Bomet, Kericho, and Nakuru counties.

Characteristic	Desirable range*	Bomet, $N = 60$	Kericho, $N = 90$	Nakuru, $N = 70$	p-Value
DO (mgL^{-1})	5	16.9 ± 0.7	14.9 ± 0.3	12.5 ± 0.5	<0.001
Temperature (°C)	20–30	22.22 ± 0.32	25.22 ± 0.31	23.60 ± 0.29	<0.001
pH	6.5–9	7.22 ± 0.08	7.79 ± 0.12	9.40 ± 0.10	<0.001
Phosphates (mgL^{-1})	0.01–3	0.74 ± 0.22	1.11 ± 0.13	0.12 ± 0.01	<0.001
Electrical conductivity (μS/cm)	100–200	76 ± 5	52 ± 4	490 ± 44	<0.001
Turbidity (NTU)	30–80	67 ± 4	36 ± 3	53 ± 3	<0.001
Nitrite (NO_2) (mgL^{-1})	<0.02	0.07 ± 0.01	0.06 ± 0.00	—	0.8
Nitrates (NO_3) (mgL^{-1})	0–200	13 ± 2	29 ± 2	1 ± 0	<0.001
Carbonate hardness ($CaCO_3$) (mgL^{-1})	50–150	60 ± 3	26 ± 2	—	<0.001
Sulphates (SO_4) (mgL^{-1})	30–180	27 ± 2	41 ± 3	—	0.007

Key: NTU, nephelometric turbidity unit; NO_2, nitrite; DO, dissolved oxygen; mgL^{-1}, milligrams per litre; NO_3, nitrate; $CaCO_3$, calcium carbonate; SO_4, sulphate. *Desirable range adapted from Bhatnagar and Devi [24]. One-way analysis of variance (ANOVA) was used.

cycle like nematodes, cestodes, digenean trematodes, and acanthocephalans [9]. In culture systems, the sanitary conditions of concrete ponds and plastic tanks ponds can easily be controlled and usually have a low prevalence compared to other culture systems. In Makurdi, Benue State, Nigeria, Omeji et al. [33] observed that concrete ponds had a lower prevalence of 20% of endoparasite infestations compared to earthen ponds at 60%. In this study, 15% of fish reared in concrete ponds and 30% in plastic tanks were infected by two parasite genera, while liner ponds had 35.45% which could be attributed to poor aquaculture practices such as poor sanitary measures of sharing of equipments (such fishing nets) between farms [14]. Earthen ponds had the highest prevalence of 52.5% like in Nigeria [33]. This could possibly be due to having natural water environments of overgrown vegetation (weed), presence of scavenging piscivorous birds around the ponds which are definitive hosts of fish helminth parasites; and presence of intermediate hosts like snails [34] as reported by Murugami et al [9]. in Kirinyaga County, Kenya.

Dactylogyrus sp. with a scalloped head with anterior eyes spots was the only monogenean [35] found on fish gills. These are oviparous parasites with direct life cycle [22]. Kericho County had a prevalence of 28.9%, Bomet 10%, and Nakuru 4.3%, and the differences were statistically significant (<0.001). The high prevalence of *Dactylogyrus* sp. in Kericho could be due to tilapia overpopulation in ponds as farmers practised mixed sex culture that can result in prolific inbreeding of fish [35]. These parasites multiply rapidly in ponds under high stocking densities. High stocking density is commonly associated with the buildup of high ammonia level metabolites (either from unconsumed proteinaceous feeds fed to fish or nitrogenous wastes from fish). Subsequently, high level of organic compounds is a risk factor for increasing the hatching of monogenea eggs, consequently increasing the parasite infestation in the ponds [35]. In culture systems, earthen ponds had the highest prevalence of 36.25%, concrete 20%, and liner 3.64%, and these were statistically significant (<0.001). This was attributed to poor sanitary conditions before stocking, and it is also more difficult to control water parameters in earthen ponds, especially ammonia which interfere with water pond water quality [9]. Poor water quality in ponds especially the increased levels of nitrates, sulphates, and phosphates was positively correlated with *Dactylogyrus* sp. in the study. Further, temperatures in the study area were within normal range and were positively correlated with *Dactylogyrus* sp. Allalgua et al. [36] reported that *Dactylogyrus* sp. tends to reproduce rapidly at higher

Table 4: Effect of water quality parameters on the occurrence of fish parasites.

Parasites	Nitrites (mgL^{-1})	Nitrates (mgL^{-1})	$CaCo^3$ (mgL^{-1})	Sulphates (mgL^{-1})	DO (mgL^{-1})	Temp (°C)	pH	PO_4 (mgL^{-1})	Electrical conductivity (μS/cm)	Turbidity (NTU)
Diplostomum	−1.00	0.15	−1.00	1.00	−0.80	0.87	0.66	−0.08	0.40	−0.87
Acanthocephalus	NA	−0.82	NA	NA	−0.89	−0.05	0.97	−0.93	1.00	0.06
Dactylogyrus	−1.00	0.91	−1.00	1.00	0.07	0.88	−0.28	0.79	−0.56	−0.89
Euclinostomum	NA	−0.82	NA	NA	−0.89	−0.05	0.97	−0.93	1.00	0.06
Riboscyphidia	−1.00	0.95	−1.00	1.00	0.17	0.83	−0.37	0.85	−0.63	−0.84
Epistyis	−1.00	0.94	−1.00	1.00	0.15	0.84	−0.36	0.84	−0.62	−0.85
Trichodina	−1.00	−0.80	−1.00	1.00	−0.91	−0.01	0.98	−0.92	1.00	0.03
Contracaecum	−1.00	0.40	−1.00	1.00	−0.61	0.97	0.43	0.18	0.14	−0.97
Paracamallanus	−1.00	0.96	−1.00	1.00	0.22	0.80	−0.42	0.87	−0.67	−0.81
Camallanus	−1.00	0.90	−1.00	1.00	0.05	0.89	−0.26	0.78	−0.54	−0.89

Key: PO_4, phosphates; DO, dissolved oxygen; mgL^{-1}, milligrams per litre; $CaCO_3$, calcium carbonate; Temp, temperature; (μS/cm)-microsiemens per centimeter; NTU, nephelometric turbidity units.

temperatures in summer seasons relative to low temperatures in winter seasons.

Ciliated ecto-commensal parasites, namely, *Trichodina*, *Epistylis*, and *Riboscyphidia* species, were recovered from fish skins in liner and earthen ponds in Kericho and Bomet counties. *Riboscyphidia* sp. attaches itself tightly on fish skin, causing superficial damage [22]. Resultant lesions are infected by pathogenic bacteria like *Aeromonas hydrophila* leading to death of fish [22]. The intensity of infestation was very high in earthen relative to other ponds. *Epistylis* sp. has been shown to produce white and haemorrhage lesions on tips of the bony fish [22]. The skin is usually ulcerated in fish co-infected with *Epistylis* sp. and bacterial pathogens, particularly *A. hydrophila* and other Gram-negative bacteria [37]. Both *Riboscyphidia* and *Epistylis* species had positive correlations with nitrates, sulphates, temperature, and phosphates as reported by Pádua et al. [37], in which they proliferate and increase when they discharge nutrients into the aquatic environment.

Trichodina sp. that has circular denticulate ring with flat lateral projections/hooks and cup-shaped structured [35] was recovered from fish skin and fins in liner and earthen ponds in the three counties. The adhesive disk of *Trichodina* sp. has fast circular movement, which causes abrasive lesions on the host when the intensities are greater than 10 and can cause mortality in farmed fish [38]. The ectoprotozoan showed a positive correlation with sulphate content, pH, and electrical conductivity as was reported by Adamba et al. [18].

The metacercariae of *Diplostomum* sp. were found in the vitreous humour and lenses of tilapia eyes. *Diplostomum* sp. was found in Kericho (3.3%) and Nakuru counties (7.1%) and occurred at a prevalence of 20% in plastic tanks, 4.6% in liner, and 1.3% in earthen ponds. The occurrence of *Diplostomum* sp. could be attributed to farmer sourcing seeds from other farmers forgoing certified hatcheries, hence bringing to the system infested fish [6]. Earthen ponds had high prevalence and intensity because of the presence of snails that are intermediate host of *Diplostomum* sp [39]. The intensity of *Diplostomum* sp. was high in liner (4.6 ± 3.51) and least in earthen ponds (1), possibly due to sharing of farm equipment such as harvesting nets. In situations where *Diplostomum* sp. intensity is greater than 40, the metacercariae cause eye blindness, resulting to predation, reduced feeding efficiency, emaciation, and death of the fish [39, 40]. *Diplostomum* sp. occurrence was positively correlated with pond water temperature, sulphate concentration, and pH. Temperature and sulphate increase the productivity of the culture system, hence providing a stable food chain and increasing the populations of intermediates, host such as snails. High pH interferes with the immune system of fish, increasing their vulnerability to infestation by the eye fluke [18]. However, *Diplostomum* sp. occurrence had a negative correlation with dissolved oxygen (DO) as was reported by Adamba et al. [18] and was quite high in the study area.

Euclinostomum sp. was found in the kidney of tilapia in liner ponds in Nakuru at a mean intensity of 11.2 ± 2.8. Black egret birds were observed in the farm and possibly were the definitive host of *Euclinostomum* sp. Suanyuk et al. [41] reported that high intensity of metacercariae of *Euclinostomum* sp. can result to emaciation and death of fish and is of zoonotic importance [42]. *Euclinostomum* sp. showed a positive correlation with pH and electrical conductivity as was reported by Adamba et al. [18]. However, these findings disagreed with Adamba et al. [18] who reported positive correlation of *Euclinostomum* sp. with temperature which was not the case in the current study.

Three nematodes, *Contracaecum*, *Camallanus*, and *Paracamallanus* species, were recovered from the intestines of *O. niloticus*. Prevalence was low in in all study areas with most nematodes (*Contracaecum* and *Paracamallanus*) recovered in earthen ponds due to availability of intermediate hosts [35]. The high prevalence of *Camallanus* sp. in plastic tanks can be attributed to poor farm management practices like sourcing untreated/unscreened water from rivers [16]. The abundance of *Paracamallus* sp. was very high in liner ponds, which could be a result of using water from the river for fish farming by most farmers. Such source of water could have brought in feral fish infected with parasites such as *Paracamallus* sp. [35, 43]. *Paracamallanus* and *Camallanus* species were positively correlated with nitrates, sulphates, and phosphates, while *Contracaecum* sp. was positively correlated with water temperature and sulphates concentrations. Adamba et al. [18] also found positive correlation of temperature with *Contracaecum* sp. High temperature increases motility of nematode larvae and dispersion in the aquatic environment, hence increasing their infectivity to susceptible hosts [18].

Acanthocephalus sp. was found in the intestine of tilapia fish. These parasites were characterized by the presence of hooked proboscis at the anterior end. The parasites were only found in Nakuru County and in liner ponds at a prevalence of 2.9%. In this study, the occurrence of *Acanthocephalus* sp. had a positive correlation with pH and electrical conductivity. *Acanthocephalus* sp. are zoonotic parasites as documented by Duarte et al. [44].

5. Conclusions

The study demonstrates that water quality significantly influences parasitic prevalence in aquaculture systems. Therefore, it is crucial for farmers to monitor water quality parameters to mitigate parasitic infestations.

Data Availability

The data used to support the findings of this study are available upon request.

Disclosure

The research was conducted in the University of Nairobi in collaboration with WorldFish and the Norwegian Veterinary Institute. Preliminary findings of this research had been presented in Aquaculture Africa 2023, seminar in Lusaka, Zambia.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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