Journal of Aquatic Science, 2024, Vol. 7, No. 1, 1-8
Available online at http://pubs.sciepub.com/jas/7/1/1
Published by Science and Education Publishing
DOI:10.12691/jas-7-1-1

Pathology of Oreochromis Niloticus Due to Infections and Water Pollution in Kisumu and Homa Bay, Lake Victoria, Kenya

Kamundia Patrick Waweru[1,*], Mbuthia Paul Gichohi[2], Bebora Lilly[2], Njagi Lucy Wanjiru[2], Nyaga Phillip Njeru

[1]Maasai Mara University, Department of Animal Health and Production, PO. Box 861- 20500, Narok, Kenya
[2]University of Nairobi, Department of Pathology, Microbiology and Parasitology, Faculty of Veterinary Medicine, PO. Box 29053 – 00625, Nairobi, Kenya
*Corresponding author: kamundia@mmarau.ac.ke

Received December 12, 2023; Revised January 15, 2024; Accepted January 22, 2024

Abstract The study assessed the health of Nile tilapia (Oreochromis niloticus) in the Winam Gulf in Kisumu and Homa Bay, Kenya, using descriptive lesions and histopathological semi-quantitative tools. The condition factor and hepatosomatic index were calculated based on the total fish weight, standard length, and liver weight. The liver, gills, and kidneys were collected from freshly killed fish, fixed in 10% buffered formalin, and processed using standard histopathological techniques. The overall condition factor of fish was 1.12 in Kisumu while those in Homa Bay ranged between 1.23 to 1.32 and the differences was statistically significant ($p<0.05$). The mean organ indices were higher in Kisumu (liver: 4.27, gill: 3.64 and kidney: 4.47) compared to Homa Bay's (liver: 2.26, gill: 3.21 and kidney: 1.98). The most prevalent histopathological lesions in the liver were increased melanomacrophages centres aggregation (12.5%), hepatocellular fibrosis (9.7%), fatty liver degeneration (10.4%) and hepatocytic necrosis (9%). Those in gills, were leucocytic infiltration (12.5%), gill epithelial necrosis (11.8%), telangiectasia (11.1%), and gill lamellar fusion (11.1%). In the kidney the lesions were glomerular vacuolation and dilatation of the Bowman's capsule (12.5%), and vacuolation and hydropic degeneration of renal tubular epithelium (11.8%). The study provides insight into the health status of fish in Kisumu and Homa Bay and demonstrates the histopathological changes and semi-quantitative scores of lesions in tissues caused by exposure to pollutants, infections by pathogenic microorganisms, and other factors that compromise the health of the fish. The findings indicate a need for monitoring the wild fish health and water pollution levels for socio-economic development and overall ecosystem protection in the region.

Keywords: *Nile tilapia, pathological changes, histopathology, Kisumu, Homa Bay*

Cite This Article: Kamundia Patrick Waweru, Mbuthia Paul Gichohi, Bebora Lilly, Njagi Lucy Wanjiru, and Nyaga Phillip Njeru, "Pathology of Oreochromis Niloticus Due to Infections and Water Pollution in Kisumu and Homa Bay, Lake Victoria, Kenya." *Journal of Aquatic Science*, vol. 7, no. 1 (2024): 1-8. doi: 10.12691/jas-7-1-1.

1. Introduction

Wild fish face many infectious and non-infectious diseases and conditions, leading to observable macroscopic and microscopic changes in their organs. The study determined the pathological changes of select *Oreochromis niloticus* organs, and compared the lesions to previously reported lesions in other fish, and their probable impact on the fish health and welfare. Lake Victoria is a freshwater lake, with a rich diversity of flora and fauna in East Africa. Kenyan section is 6% of the total lake surface. *Oreochromis niloticus* were introduced into Lake Victoria in 1950 and 1960s to boost the declining catches [1]. Often, a question is asked why an interest in the health of wild fisheries such as the *Oreochromis niloticus* of Lake Victoria taken? The fish species is of socio-economic and ecological importance in the Lake Victoria basin. *Oreochromis niloticus* is classified as one of the most economically important fish that inhabit the lake [2]. *Oreochromis niloticus is* a teleost in the Family Cichlidae that has become a dominant tilapiine in Lake Victoria and, therefore, a species of importance as a source of dietary protein, socio-economic driver, and creates employment to populations living around the Lake Victoria basin [3].

The pathological changes in fish manifest at the macroscopic and microscopic levels, and are a result of varied aetiologies which may range from infectious causes such as microbial and parasitic infections to non-infectious causes such as trauma, nutritional deficiencies and chemical pollution. Estrogenic endocrine disrupting chemicals [4] and potentially pathogenic microbes such as *Aeromonas*, *Staphylococcus* and *Streptococcus* were recovered in Lake Victoria waters and fish (personal communication). These alterations impact the well-being and overall health of the fish. Therefore, histopathology becomes a vital tool for the assessment of aquatic pollution and the health of fish. Pollution of the lake has however raised ecological concerns, which also leads to concerns on the welfare of the aquatic organism that includes fish. There have been numerous reports of inorganic and organic pollutants in Lake Victoria that include pesticides, heavy metals and endocrine disrupting chemicals in either water or fish [5]. Pathogenic microbes have also been isolated from water and fish obtained from the lake [6]. Both the pathogenic microbes and chemical pollutants are a threat to the fish, and their effects on the *Oreochromis niloticus*' health are unknown. Fish have also been proposed as environmental sentinels, and hence used as an indicator of aquatic ecosystem health [7]. The histopathology, biomarker of changes due to irritant stimulus, has been used as a tool to assess the health of fish as a result of the effects of various pollutants and infectious organisms [8]. However, no assessment of the effect of these stressor stimuli on the health of the fish at cellular levels through histopathology has been attempted on *Oreochromis niloticus* found in the Lake Victoria waters.

There has been increased environmental pollution in the Lake Victoria's catchment area, and this has arisen from the chemical and microbial pollution from industries, urban and peri-urban settlements, and agricultural activities, which discharge their wastes into the lake [9]. The pollutants include a wide range of chemicals such as PCBs, endocrine disrupting chemicals, heavy metals, and microbial pollution. The pollutants have a varied adverse effect on the aquatic animal in the lake, and these are a serious threat to the overall ecosystem health [10]. To date, there has been no other investigative study on the occurrence of histopathological lesions in the *O. niloticus* species of Lake Victoria, Kenya; especially as an indicator of endpoint effects of pollutants' exposure. This study, therefore, is instrumental in mapping the histopathology of the *Oreochromis niloticus* of Lake Victoria waters.

Histopathology is also crucial for the assessment of acute and chronic exposure to chemicals in water by demonstrating cellular alterations because of organic and non-organic contaminants. Histopathology is a biomarker of cellular changes induced by various stressor-inducing stimuli in water such as pollutants or infectious agent. The biomarkers have been instrumental in the investigation of the effects of contaminants and microorganisms on fish organs studied, and are reported as an efficient assessment tool for the health of fish post-stimuli exposure [11]. The degree of change estimated through the extent of cellular alterations are used as biomarkers that indicate the aquatic pollution levels [12].

The gills, liver, kidney and muscles are the tissues most often used in ecological, toxicological and pathological studies of teleost fish [13]. The chemical exposure and microbial infections induce lesions in different organs. The occurrence of particular lesions in fish organs have been associated with pollution and therefore used to assess water quality. Fish liver, kidney and gills are the most used due to their metabolic and physiological functions which increase the chemical exposure and microbial infections [14,15]. The liver due to the metabolism and detoxification function has a high supply of blood that takes in toxicants to hepatocytes thus exposing them to various effects [16]. The gills are also highly vulnerable through continuous exposure to polluted water; ion transport, gas exchange, acid-base regulation and waste excretion functions [17]. The kidney role is to maintain homeostasis by excretion of nitrogen-containing waste products, managing the electrolyte and water and balance body fluids [18].

The somatic indices such as hepatosomatic indices and condition factor are used to measure the metabolic robustness of the fish; giving the health status of fish based on the metabolic state of the fish due to feed availability and water quality in an aquatic system [19].

Research gaps in fish pathology and impacts of pathogens and chemicals have been identified in the East African water bodies [20]. The objective of this study was to determine the prevalence of the histopathological lesions, the condition factor, and hepatic somatic indices of *O. niloticus* of Lake Victoria to measure fish health. The results of this study are instrumental in evaluating fish health. The monitoring of chemical pollution and ecological studies have been carried out over the years, the use of histopathology as a bioindicator has never been used to access the effect of the contaminants on *Oreochromis* spp in Lake Victoria.

2. Material and Methods

2.1. Description of the Study Site

Live fish were obtained from fishers in Kisumu and Homa Bay, in the Winam Gulf of Lake Victoria, Kenya. A total of 144 fish were collected; 109 in Kisumu and 35 in Homa Bay Figure 1. The sampling was done in five surveys; three surveys in Kisumu and two in Homa bay. These fish were examined for any gross lesions on the external surface.

The weight (in grams) was measured using a digital balance. The total length (in centimetres) of *Oreochromis niloticus* fish was then measured using a ruler to the nearest centimetre. The total length was measured from the snout to the tip of the caudal fin. The condition factor (k) was calculated using the formulas as described by [21]: $K = 100W / L^3$, where: W= Weight (g) and L=Total Length. The hepatosomatic index (HSI) calculated as described by [10]: $HSI = \frac{LW}{BW} \times 100^3$, where: LW= Liver weight (grams) and BW = Bodyweight (grams).

The fish were dissected, and any internal gross lesions noted. Pieces of the liver, gills, and kidneys were obtained, placed in a labelled container and fixed with 10% buffered formalin. They were then dehydrated through graded alcohol series (70 to 100%), cleared in xylene and embedded in paraffin. 3 to 5 µm thick paraffin sections were cut and stained with hematoxylin-eosin (H&E). The slides were observed under a light microscope (Amscope Microscope T720 model, China), and photographed with 14-megapixel Amscope Aptina Digital Camera MU1400 series, China).

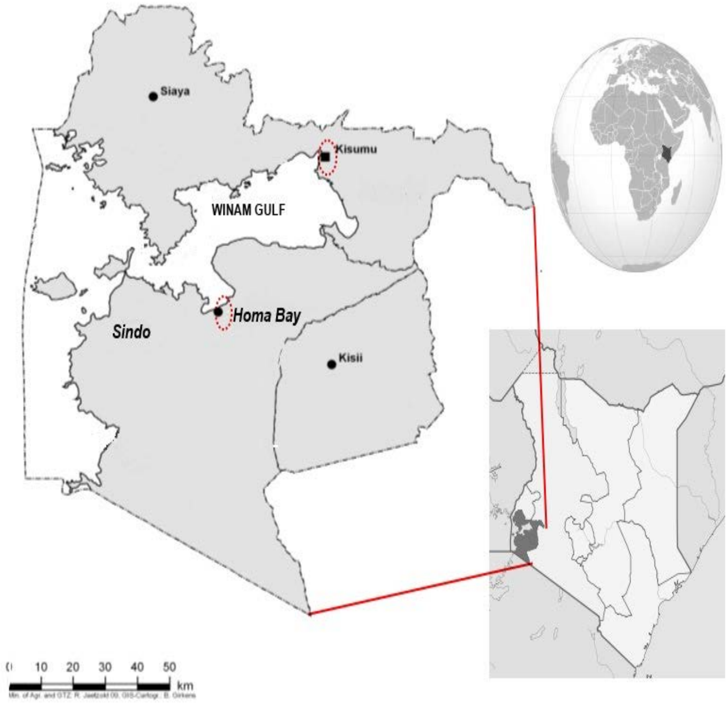

Figure 1. Study area on the Winam Gulf of Lake Victoria, Kenya on the shores of the Kisumu and Homa Bay

2.2. Semi-quantitative Analysis

The histopathological lesions were further subjected to a semi-quantitative analysis as proposed by [22], which categorised the lesions into five reaction patterns: regressive, circulatory, neoplastic and inflammatory. Each reaction pattern consists of a set of lesions that have a score value with a scale of 0 to 6, zero representing no lesion to six representing very severe lesion. The protocol also has an importance factor that for each lesion, that ranges from 1 for lesions with minimum pathological impact to 3, which represents lesion that have maximum pathological importance in the fish. The sum of the values for each specific reaction or organ is the index for reaction pattern or organ index, respectively. Therefore, the would-be an index for each of the five reaction patterns for each organ, and a sum of all the reaction patterns for each organ constitutes the organ index (IO).

2.3. Statistical Analysis

The data was entered in Microsoft Excel (Microsoft Corporation) and exported into Minitab® Statistical Software for analysis for descriptive statistics. For each parameter, differences between surveys in the Kisumu and Homa Bay in the different seasons were tested for significance by the analysis of variance (ANOVA) test. To all tests, significance was assigned for P< 0.05. Each organs' histological reaction indices were compared using the Kruskal–Wallis test followed by multiple comparisons at the statistical significance of p <0.05.

2.4. Ethical Considerations

The study was approved by Biosafety, Animal use and Ethics committee, Faculty of Veterinary Medicine, University of Nairobi (FVM BAUEC/2015/220).

3. Results and Discussion

3.1. Condition Factor and Hepatosomatic Index of Fish

The mean weight, total length and condition factor of *O. niloticus* captured at each survey during the current study are shown in Table 1.

Table 1. Oreochromis niloticus mean total length and weight, hepatosomatic index and condition factor

Survey	Homa Bay 1	Homa Bay 2	Kisumu 1	Kisumu 2	Kisumu 3	Overall Mean	p-value
N	30	21	23	33	37	144	
Length	33.46 ± 0.96	38.92 ± 1.44	34.48 ± 1.71	36.33 ± 1.37	31.26 ± 1.17	34.51 ± 0.62	(F (4,144) = 4.70, p = 0.001)
Weight	520.1 ± 47.4	746.4 ± 89.9	581.31 ± 91.7	794.11 ± 93.5	427.3 ± 52.8	601.8 ± 35.2	(F (4,144) = 4.62, p = 0.002)
HSI	1.82 ± 0.09	1.72 ± 0.12	1.78 ± 0.09	1.70 ± 0.10	1.67 ± 0.12	1.74 ± 0.05	(F (4,144) = 0.38, p = 0.83)
CF	1.30 ± 0.03	1.14 ± 0.02	1.24 ± 0.06	1.47 ± 0.04	1.24 ± 0.05	1.29 ± 0.02	(F (4,144) = 7.38, p = .0001)

Key: HSI-Hepatosomatic index, CF- Condition factor

Table 2. Prevalence of histopathological lesions in the gills, livers and kidneys of Oreochromis niloticus from the Winam Gulf

Gills		LCI	GEN	TEL	GLF	CON	MCH	ICH	
	KSM 1 (n=19)	10.5	10.5	15.8	26.3	5.3	10.5	0.0	
	KSM 2 (n=21)	19.1	14.3	0.0	9.5	0.0	9.5	0.0	
	KSM 3 (n=69)	14.5	11.6	13.0	4.4	10.1	7.3	8.7	
	HB 1 (22)	0.0	13.6	9.1	18.2	13.6	0.0	4.6	
	HB 2 (n=13)	15.4	7.7	15.4	15.4	7.7	7.7	0.0	
	Mean	***12.5***	***11.8***	***11.1***	***11.1***	***8.3***	***6.9***	***4.9***	
Liver		MMC	FBS	FLD	HCN	NCA	IN/H	CON	LCD
	KSM 1 (n=19)	0.0	10.5	5.3	5.3	15.8	5.3	0.0	0.0
	KSM 2 (n=21)	4.8	0.0	9.5	9.5	0.0	14.3	9.5	0.0
	KSM 3 (n=69)	15.9	14.5	14.5	11.6	7.3	5.8	2.9	4.4
	HB 1 (22)	9.1	4.6	4.6	4.6	4.6	0.0	4.6	0.0
	HB 2 (n=13)	15.4	7.7	7.7	7.7	7.7	0.0	0.0	0.0
	Mean	***12.5***	***9.7***	***10.4***	***9.0***	***6.9***	***5.6***	***3.5***	***2.1***
Kidney		GVB	VHE	MMC	LCI	GNA	ICN	HMG	
	KSM 1 (n=19)	10.5	15.8	10.5	0.0	0.0	0.0	0.0	
	KSM 2 (n=21)	19.1	4.8	4.8	4.8	9.5	0.0	0.0	
	KSM 3 (n=69)	13.0	8.7	10.1	5.8	2.9	2.9	1.5	
	HB 1 (22)	4.6	22.7	13.6	0.0	0.0	0.0	0.0	
	HB 2 (n=13)	14.3	14.3	14.3	0.0	0.0	0.0	0.0	
	Mean	***12.5***	***11.8***	***10.4***	***3.5***	***2.8***	***1.4***	***0.7***	

Gills: LCI=Leucocytes infiltration, GEN = Gill epithelial cell necrosis, TEL= Telangiectasia, GLF = Gill lamellar fusion, CON = Blood congestion, MCH=Mucous cell hyperplasia, IMC =Increase of mucous cells, **Liver:** MMC = Melanomacrophages aggregation and other pigmentations, FBS = Fibrosis, FLD = Fatty liver degeneration, HCN= Hepatic Cell necrosis, NCA = Nuclear alterations, IN/H= Inflammation/Hepatitis, CON = Congestion, LCD= Liver cords disruption, **Kidney:** GVB = Glomerulus vacuolation and dilatation of the Bowman's capsule, VHE= Vacuolation and hydropic degeneration of renal tubular epithelium, MMC= Melanomacrophages aggregation and other pigmentations, LCI = Leucocytic infiltration, GNA = Glomerulus nuclear alterations, ICN= Interstitial cell necrosis, HMG = haemorrhages

Table 3. Mean organ indices of the semi-quantitative histopathological assessment of Winam Gulf's *Oreochromis niloticus*

Site	N	Mean Liver Index	Mean Gill Index	Mean Kidney Index	Mean Fish Index
KISUMU 1	19	5.87 ± 1.84	3.35 ± 1.32	4.48 ± 1.92	13.70± 2.91
KISUMU 2	21	3.42 ± 1.02	4.30 ± 1.05	2.70 ± 1.30	10.42±2.02
KISUMU 3	69	2.57 ± 0.87	2.46 ± 0.94	3.32 ± 1.26	8.16 ± 1.66
HOMA BAY 1	22	3.20 ± 0.99	3.47 ± 1.36	6.07 ± 2.11	12.57 ± 2.48
HOMA BAY 2	13	5.19 ± 1.19	3.76 ± 1.44	3.33 ± 1.93	12.29 ± 2.60
F, P-Value		1.34, 0.257	0.43,0.783	0.67, 0.615	0.99, 0.415

3.2. Macroscopic and Microscopic Findings

Major macroscopic finding found were an abscess in the peritoneal cavity of a fish in Kisumu that had pus-like material, extensive adhesions and destruction of tissue. The microscopic picture of the tissue from the fish showed purulent inflammation with several heterophils.

The pathological lesions observed in the liver hepatocytes, and the prevalence of the various pathologies differed between the sites. The melanomacrophage centres (MMCs) aggregation (Figure 2a) were found in all surveys except Kisumu 1. The melanomacrophages aggregation located near the centro-lobular veins of the hepato-pancreas circumscribed by a thin layer of connective tissue. The melanomacrophages varied in size, and some had diffuse distribution in the liver parenchyma, whereas others had focal distribution, especially around the hepatopancreases. Other pigmentations observed were the hemosiderin deposits. Single-cell and focal necrosis was observed, which was accompanied by sinusoidal cytolysis, characterised by loss of hepatic cells (Figure 2b). In some fish, focal necrosis of the pancreatic tissue was also noted. Nuclear alterations observed were nuclear enlargement and nucleus degeneration (Figure 2c), leading to a total loss of the nucleus. Significant circulatory disturbances observed were congestion of both hepatic and pancreatic vessels and congestion within the sinusoids. A thrombus in a blood vessel was also observed in a hepatic vessel (Figure 2d). Fibrosis was denoted by the presence of fibrotic tissue and fatty liver degeneration. The fatty degeneration was characterised by hepatocytes that were filled with lipid deposits and a nucleus located at the periphery. Inflammation, congestion of the sinusoids and general disruption of the liver cord structure were also noted. Hepatitis characterised by the presence of focal and diffusely distributed leukocytes. Other lesions were vacuolated hepatocytes with condensed nuclei placed at the periphery, which consisted of liver hepatocytes with depleted lipid reserves interspersed with pigmented macrophage aggregates.

The histopathological changes associated with the gills of *O. niloticus* included leucocytic infiltration, gill epithelial cell necrosis, and telangiectasia. Leucocytic infiltration of the gills entailed the presence of leukotic cells in the filament epithelium, epithelial lifting of gills (Figure 3a). Telangiectasia characterised by swollen secondary lamella was observed (Figure 3b). Distal hyperplasia of the secondary lamella epithelium was noted in some fish. Circulatory disturbances noted in the gills included stasis of the central venous sinus and congestion of gill capillaries. Epithelial cell necrosis was observed on the secondary gill lamella. Other significant lesions observed were gill lamellar fusion and blood congestion of the gill blood vessels.

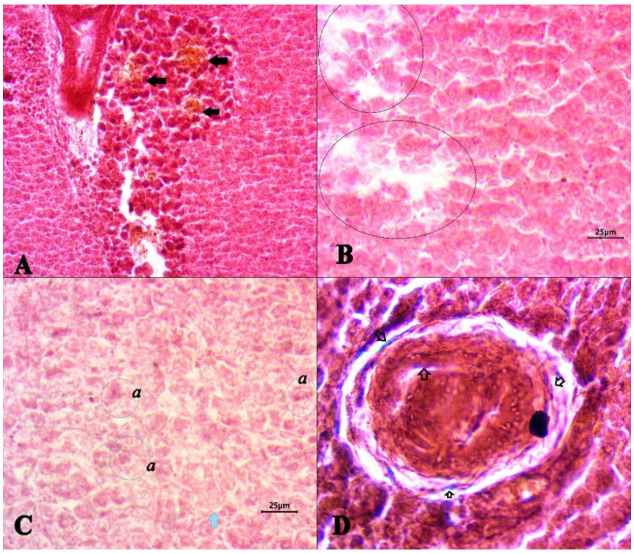

Figure 2. A- Melanomacrophages centres interspersed in the pancreatic acinar cells (black arrows) (H&E, ×800), B- coagulative necrosis showing hepatocyte and sinusoid cytolysis (H&E, x1000), C- hepatocyte nucleus degeneration (blue arrow), enlarged and eosinophilic nucleus (a) and hepatocyte vacuolation and degeneration (H&E, x1000), D- Thrombosis in a vein, showing the thin endothelial layer (black arrows) (H&E, ×2000)

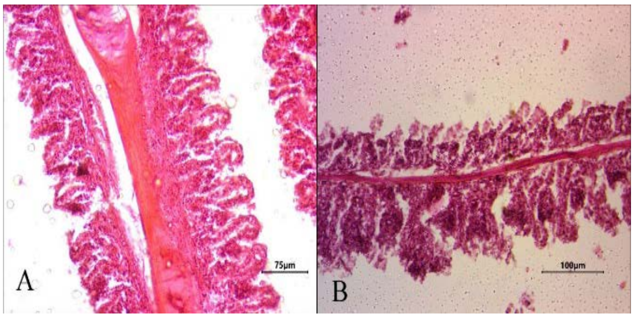

Figure 3. A- Epithelial lifting of gill lamella (H&E, X2000), B- Telangiectasia) (H&E, x2000)

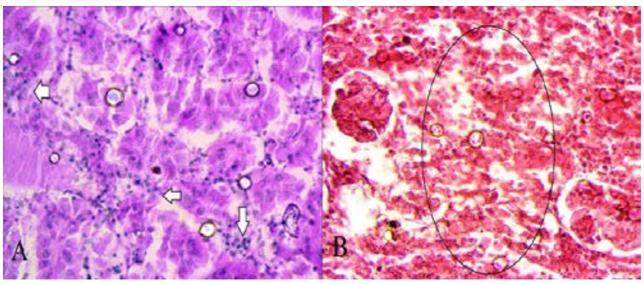

Figure 4. A-Diffuse nephritis in the kidney (white arrows): Inflammatory cells interspersed in the interstitial tissue of the kidney (×1000, H & E), B- Destruction of the hemopoietic tissue and interstitial necrosis (×800, H & E)

The most common histopathological lesions of the kidney were: glomerulus vacuolation and dilatation of the Bowman's capsule. Cases of nephritis characterised by leucocytic infiltration, interstitial cell destruction and necrosis were noted (Figure 4a). The vacuolation of the glomerulus was characterised by shrinking and destruction of the glomerular tuft, renal tubule cell vacuolation and hydropic degeneration, and melanomacrophages aggregation. The renal tubule cell vacuolation entailed the renal tubules' epithelium manifesting a vacuolated cytoplasm, a form of tubular cell degeneration. The glomerulus vacuolation was characterised by degeneration and shrinking of the glomerulus (Figure 4b). The melanomacrophage centres were observed to be interspersed in the renal interstitial as a black or dark pigmentation. Other pigmentations noted in the kidney were hemosiderin deposits. Nuclear alterations were pointed out in the glomeruli and renal tubules epithelial cells and haemorrhages.

3.3. Semi-quantitative Pathological Analysis

Table 1 shows the mean histopathological indices from the fish organs and the overall mean fish index for each survey. The means of the reaction indices were not significantly different among the sites and seasons.

The current study provides insight into the histopathological lesions of O. niloticus and a baseline of the health of the fish obtained from the two study sites in Lake Victoria's Winam Gulf, Kisumu, and Homa Bay. The histopathological changes were observed in the most sensitive organs (liver, gills and kidneys) in fish which were induced by environmental pollution and infections by pathogens.

The mean values of condition factor and hepatosomatic index were within the normal range of O*reochromis niloticus* [21] and there was no significant difference between the surveys conducted in Kisumu and Homa Bay indicating there was no significant fluctuation between the seasons. The mean condition factor in all the surveys was greater than 1, which indicates a good nutritional status of the fish [23]. Goede and Barton reported fluctuations in CF as a reflection of depleted energy reserves. The hepatosomatic index has been used as a bioindicator of water pollution in ecotoxicology studies [24]. The increased hepatosomatic index is associated with increased liver size due to either hypertrophy or hyperplasia, and other pathological destruction of the liver. In this study, the mean HSI in the five surveys in Kisumu and Homa Bay ranged between 1.67 to 1.82, which is comparable to the species averages of a HSI which is approximately 2% of the body weight [25]. Experimental studies have recorded lower or higher HSI of in fish exposed to pollutants [25,26], which indicates the role the pollutants play in the HSI.

Most of the histopathological lesions of the investigated *O. niloticus* organs observed in both Kisumu and Homa Bay, except for a few varied in prevalence. Histopathological lesions were like lesions in fish obtained from polluted waters globally as reported in other studies (8,18,22) and are a manifestation of complex interactions of stressors. For example, gill lesions have been attributed to exposure to toxic chemicals and parasites [27]. Some gill pathology changes in fish have also been attributed to bacteria associated infections and exotoxins. [28] reported bacterial infections in freshwater fish resulted in epithelial hyperplasia leading to fusion of secondary lamellae. The net effect is decreased respiratory surface and diminished respiratory efficiency.

A variety of lesions in the liver, gills and kidney of *Oreochromis niloticus* examined were categorised as progressive, regressive, inflammatory, and circulatory disturbances. Most of the lesions were found in organs in the various surveys in both Homa Bay and Kisumu. A comparison of the prevalence of lesions in Kisumu and Homa Bay sites demonstrates the distribution of lesions among the fish organs; although some lesions occurred in a few fish. There were variations in the prevalence of lesions between the sites and seasons but no significant differences. The liver and the gill had the highest prevalence, and the kidney had the least. The high lesion prevalence in the liver and gill indicates their exposure to the pollution elements by their function. Previous studies have shown that both the liver and gills are essential biomarkers of toxic pollutants in water [29].

The liver is a metabolic organ processing many metabolites that include chemical pollutants and hence their higher risk of exposure. In this study, hepatocytes in the liver exhibited several lesions such as melanomacrophage infiltrations, fatty liver degeneration, hepatic cell necrosis, and fibrosis. These lesions have been reported in other studies due to exposure to environmental contaminants. Example is hepatocytes fibrosis, necrosis and fatty liver degeneration which are lesions of severe magnitude and associated with exposure of fish to heavy metals [18]. Increased size and numbers of melanomacrophage centres in the liver and kidney have been linked to increased detoxification action by these organs on exposure to pollutants [30,31]. The occurrence and size of melanomacrophage centres are dependent on the fish species, tissue affected, and amount of insult the tissues have been exposed to [32,33]. Melanomacrophages have been reported to increase with age, starvation, disease and exposure to pollutants. Therefore, other contributing factors cannot be ruled out in this study [34,35]. Melanomacrophages and liver hepatocyte vacuolation which were observed in this study have been attributed to pathogenic bacteria such as *Aeromonas hydrophila*, *Streptococcus iniae* and *S. agalactiae* [36,37] some which were observed in this study.

Concerning the gill histopathology, it can show the extent of damage, and if severe poses a danger by lowering the fish's respiratory capacity. Gills are highly sensitive to changes in the aquatic environment, and the presence of pollutants has a significant effect [38]. Their large surface area, which by design is to increase the area for gaseous exchange makes the gills vulnerable to contaminants in water [39]. Various pollutants have different effects on the gills; for example, copper changes the morphology and ultrastructure of gills [40] heavy metal ions cause cellular damage which impedes respiration and osmoregulation [41].

Renal tissue lesions such as glomerular destruction and dilatation of the Bowman's capsule were also described in fish exposed to xenobiotics [42]. Lesions such as hydropic vacuolar degeneration and necrosis of the tubular epithelium have been reported in cases of toxicity with hydrocarbons, heavy metals and other environmental contaminants [31,34]. The result of damage to the kidney tissue is inefficient ion reabsorption which would lead to loss of ions in a freshwater fish such as *O. niloticus*.

The semi-quantitative evaluation of the organs reveals high organ indices for some surveys than others, while others had moderate indices which indicate less alteration. It was noted that the liver and gill which had higher lesion prevalence had a mean index comparable to the kidneys that had lower prevalence. The kidney index is associated with lesions whose relative importance to the wellbeing of fish is more weighted than the gill and liver lesions.

Pathology caused by microbial infections may manifest as leucocytic infiltrations. Numerous cases of leucocytic infiltrations were noted in the hepatic, renal and respiratory tissues, at varying prevalence. Inflammation is a pathophysiological process as a result of several stressors such as trauma, bacterial, viral infections and chemical or toxicant injury [34].

Histopathological lesions were observed in all organs in the study indicating that the tissues are exposed to various stressors; chemical, microbial and probably some idiopathic etiology. Some of the lesions could be attributed to pollutants and microbial infections. The lesions were seen in both Kisumu and Homa Bay, though with varying prevalence's. The data from the study indicates that fish in Kisumu are slightly more affected than the fish in Homa Bay. The study indicates that histopathology is an important biomarker in the study of the potential effects of pollutants in an aquatic system.

The cells of fish exposed to pollutants undergo adaptive changes initially, and irreversible cellular damages as the exposure become chronic. Further investigation is recommended on the *Oreochromis niloticus* to determine the effects of significant pollutants on the fish and develop a better understanding of the adverse effects of pollution of the *Oreochromis* physio-biology. The distribution of the lesions in the organs sampled indicate that the *Oreochromis niloticus* is a useful sentinel organism that can be used to monitor histopathological changes induced by chemicals or microorganisms. The study concurs with other studies which have used histopathology as an ecotoxicological tool for evaluation and assessment of the toxicological impact on organisms in the aquatic environment by quantification of the damage on cells, tissues and organs [16,43,44]. These results provide a baseline for future studies of *Oreochromis niloticus* in the lake. There is also a need to establish the baseline databases for other species in the lake. The presence of the histopathological lesions has long-term implications for fish health, and therefore, studies on the same are recommended.

4. Conclusions

The histopathology lesions of *Oreochromis niloticus* obtained in both Kisumu and Homa Bay are biomarkers of damage caused by pathogens and environmental pollutants that include chemicals, and hence is an indicator that the health of the *Oreochromis niloticus* is compromised. Though not possible to identify the definitive causative agents of the pathology in this study, it's clear that the fish are being exposed to stressful factors which results in a manifestation of pathology. This study recommends further research work to increase the monitoring of the effects the pathogens and aquatic pollution has on fish and other aquatic species because of environmental pollution.

ACKNOWLEDGEMENTS

The Inter-University Council of East Africa (IUCEA) project partially funded this work. We also acknowledge the technicians in the histopathology laboratory in the Department of Pathology, Microbiology and Parasitology, Faculty of Veterinary Medicine of the University of Nairobi and School of Natural Resources, Environmental Studies and Agriculture of the Maasai Mara University.

Statement of Competing Interests

The authors declare that they have no competing interests that could have influenced the conduct of this study or the interpretation of its results.

References

[1] Sayer, C. Máiz-Tomé, L. & Darwall, W. "Freshwater biodiversity in the Lake Victoria Basin: Guidance for species conservation, site protection, climate resilience and sustainable livelihoods." Cambridge, Gland: International Union for Conservation of Nature. 50-52. 2018. 10.2305/IUCN.CH.2018.RA.2.en.

[2] Yongo, E., Outa, N., Kito, K., & Matsushita, Y. "Studies on the biology of Nile tilapia (*Oreochromis niloticus*) in Lake Victoria, Kenya: in light of intense fishing pressure." *African Journal of Aquatic Science*, *43*(2), 195–198.

[3] Yongo, E., Outa, N., Kito, K., & Matsushita, Y. "Some aspects of the biology of Nile perch, *Lates niloticus*, in the open waters of Lake Victoria, Kenya." *Lakes and Reservoirs: Research and Management*, *22*(3), 262–266.

[4] Kamundia W, Mbuthia P., Njagi L., Bebora L., Nyaga P. & Mdegela R. Quantification of Estrogenic endocrine disrupting chemicals in river estuary and lake water from select sites in Winam Gulf of Lake Victoria, Kenya. European Journal of Pharmaceutical and Medical Research. 10 (9),81-87. 2023.

[5] Abong'o, D. A., Wandiga, S. O., & Jumba, I. O. "Occurrence and distribution of organochlorine pesticide residue levels in the water, sediment and aquatic weeds in the Nyando River catchment, Lake Victoria, Kenya." *African Journal of Aquatic Science*, *43*(3), 255–270. 2018.

[6] Onjong, H. A., Ngayo, M. O., Mwaniki, M., Wambui, J., & Njage, P. M. K "Microbiological Safety of Fresh Tilapia (*Oreochromis niloticus*) from Kenyan Fresh Water Fish Value Chains." Journal of Food Protection,81 (12). 1973-1981.

[7] Karlsson, O. M., Waldetoft, H., Hållén, J., Malmaeus, J. M., & Strömberg, L. "Using Fish as a Sentinel in Risk Management of Contaminated Sediments." Archives of Environmental Contamination and Toxicology, 84(1), 45-72. 2023.

[8] Flores-Lopes, F., & Thomaz, A. T. "Histopathologic alterations observed in fish gills as a tool in environmental monitoring." Brazilian Journal of Biology, 71, 179-188.

[9] Kundu, R., Aura, C. M., Nyamweya, C., Agembe, S., Sitoki, L., Lung'ayia, H. B. O., Ongore, C., Ogari, Z., & Werimo, K. "Changes in pollution indicators in Lake Victoria, Kenya and their implications for lake and catchment management." *Lakes and Reservoirs: Research and Management*, *22*(3), 199–214.

[10] Liebel, S., Tomotake, M., & Oliveira-Ribeiro, C. A. "Fish histopathology as a biomarker to evaluate water quality." *Ecotoxicology and Environmental Contamination*, *8*(2), 9–15.

[11] Wolf, J. C., Baumgartner, W. A., Blazer, V. S., Camus, A. C., Engelhardt, J. A., Fournie, J. W., Frasca, S., Groman, D. B., Kent, M. L., Khoo, L. H., Law, J. M., Lombardini, E. D., Ruehl-Fehlert, C., Segner, H. E., Smith, S. A., Spitsbergen, J. M., Weber, K., & Wolfe, M. J. "Nonlesions, Misdiagnoses, Missed Diagnoses, and Other Interpretive Challenges in Fish Histopathology Studies." *Toxicologic Pathology*, *43*(3), 297–325.

[12] Aldoghachi, M. A., Azirun, M. S., Yusoff, I., & Ashraf, M. A. "Ultrastructural effects on gill tissues induced in red tilapia *Oreochromis sp.* by waterborne lead exposure." *Saudi Journal of Biological Sciences*, *23*(5), 634–641.

[13] Heier, L. S., Lien, I. B., Strømseng, A. E., Ljønes, M., Rosseland, B. O., Tollefsen, K. E., & Salbu, B. "Speciation of lead, copper, zinc and antimony in water draining a shooting range-Time dependant metal accumulation and biomarker responses in brown trout (*Salmo trutta L.*)." *Science of the Total Environment*, *407*(13), 4047–4055.

[14] Majnoni, F., Mansouri, B., Rezaei, M., & Hamidian, A. H. "Metal concentrations in tissues of common carp, *Cyprinus carpio*, and silver carp, *Hypophthalmichthys molitrix* from the Zarivar Wetland in Western Iran." *Archives of Polish Fisheries*, *21*(1), 11–18.

[15] Pokorska, K., Protasowicki, M., Bernat, K., & Kucharczyk, M. "Content of metals in flounder, *Platichthys flesus L*., and Baltic herring, *Clupea harengus membras L*., from the southern Baltic Sea." *Archives of Polish Fisheries*, *20*(1), 51–53.

[16] Yancheva, V., Velcheva, I., Stoyanova, S., & Georgieva, E. "Histological biomarkers in fish as a tool in ecological risk assessment and monitoring programs: A review." In *Applied Ecology and Environmental Research* (Vol. 14, Issue 1).

[17] Vergilio, C. S., Moreira, R. V, Carvalho, C. E. V., & Melo, E. J. T. "Histopathological effects of Mercury on male gonad and sperm of tropical fish *Gymnotus carapo* in vitro." *E3S Web of Conferences*, *1*, 3–6.

[18] Camargo, M. M. P., & Martinez, C. B. R. "Histopathology of gills, kidney and liver of a Neotropical fish caged in an urban stream." *Neotropical Ichthyology*, *5*(3), 327–336.

[19] Hammock, B. G., Hobbs, J. A., Slater, S. B., Acuña, S., & Teh, S. J. "Contaminant and food limitation stress in an endangered estuarine fish." *Science of the Total Environment*, *532*, 316–326.

[20] Akoll, P., & Mwanja, W. "Fish health status, research and management in East Africa: Past and present." African Journal of Aquatic Science, 37(2), 117–129.

[21] Migiro, K. E., Ogello, E. O., & Munguti, J. M. "The length-weight relationship and condition factor of Nile tilapia (*Oreochromis niloticus L.*) broodstock at Kegati Aquaculture Research Station, Kisii, Kenya." International Journal of Advanced Research, 2(5), 777-782. 2014.

[22] Bernet, D., Schmidt, H., Meier, W., Burkhardt-Holm, P., & Wahli, T. "Histopathology in fish: Proposal for a protocol to assess aquatic pollution." *Journal of Fish Diseases*, *22*(1), 25–34.

[23] Datta, S. N., Kaur, V. I., Dhawan, A., & Jassal, G. "Estimation of length-weight relationship and condition factor of spotted snakehead *Channa punctata* (Bloch) under different feeding regimes." *SpringerPlus*, *2*(1), 1–5.

[24] Araújo, F. G., Morado, C. N., Parente, T. T. E., Paumgartten, F. J. R., & Gomes, I. D. "Biomarkers and bioindicators of the environmental condition using a fish species (Pimelodus maculatus Lacepède, 1803) in a tropical reservoir in Southeastern Brazil." *Brazilian Journal of Biology*, *78*(2), 351–359.

[25] Al-Ghais, S. M. "Acetylcholinesterase, glutathione and hepatosomatic index as potential biomarkers of sewage pollution and depuration in fish." *Marine Pollution Bulletin*, *74*(1), 183–186.

[26] Çiftçi, N., Ay, Ö., Karayakar, F., Cicik, B., & Erdem, C. "Effects of zinc and cadmium on condition factor, hepatosomatic and gonadosomatic index of *Oreochromis niloticus*." *Fresenius Environmental Bulletin*, *24*(11A), 3871–3874. 2015.

[27] Alazemi, B. M., Lewis, J. W., & Andrews, E. B. "Gill Damage in the Freshwater Fish *Gnathonemus Petersii* (Family_ Mormyridae) Exposed to Selected Pollutants_ An Ultrastructural Study." Environmental Technology, 17 (3) , 225–238. 1996.

[28] Lewis, J. W., Morley, N. J., Drinkall, J., Jamieson, B. J., Wright, R., & Parry, J. D. "Toxic effects of Streptomyces griseus spores and exudate on gill pathology of freshwater fish." *Ecotoxicology and Environmental Safety*, *72*(1), 173–181.

[29] Georgieva, E., Stoyanova, S., Velcheva, I., Vasileva, T., Bivolarski, V., Iliev, I., & Yancheva, V. "Metal effects on histological and biochemical parameters of common rudd

(*Scardinius erythrophthalmus* L.).” *Archives of Polish Fisheries*, *22*(3), 197–206.

[30] Hassaninezhad, L., Safahieh, A. R., Salamat, N., Savari, A., & Majd, N. E. “Assessment of gill pathological responses in the tropical fish yellowfin seabream of the Persian Gulf under mercury exposure."*Toxicology Reports*, *1*, 621–628.

[31] Salamat, N., & Zarie, M. “Using of Fish Pathological Alterations to Assess Aquatic Pollution: A Review.” *World Journal of Fish and Marine Sciences*, *4*(3), 223–231.

[32] Bruno, D. W. “Systemic pathology of fish.” In *Fisheries Research* (Vol. 9, Issue 2).

[33] Butchiram, M. S., Vijaya Kumar, M., & Tilak, K. S. “Studies on the histopathological changes in selected tissues of fish *Labeo rohita* exposed to phenol.” *Journal of Environmental Biology*, *34*(2), 247–251. 2013.

[34] Roberts, R. J. *Fish Pathology*. Wiley. 2012. 67-70.

[35] Sales, C. F., Silva, R. F., Amaral, M. G. C., Domingos, F. F. T., Ribeiro, R. I. M. A., Thomé, R. G., Santos, H. B., & Wang, L. W. and W. C. and Y. J., and C. “Comparative histology in the liver and spleen of three species of freshwater teleost.” *Neotropical Ichthyology*, *15*(7), 74017. http://stacks.iop.org/1748-9326/11/i=7/a=074017. 2017.

[36] Chen, C. Y., Chao, C. B., & Bowser, R. R. “Comparative histopathology of *Streptococcus iniae* and *Streptococcus agalactiae*-infected tilapia.” *Bulletin of the European Association of Fish Pathologists*, *27*(1), 2–9. 2007.

[37] Azadbakht F, Shirali, S., Ronagh, M. T., & Zamani, E. “Effect of *Aeromonas hydrophila* in the tissue structure of the liver and immune organs in *Acanthopagrus latus*.” *Veterinary Researches and Biological Products*, *31*(3), 88–95. 2018.

[38] Strzyzewska, E., Szarek, J., & Babinska, I. “Morphologic evaluation of the gills as a tool in the diagnostics of pathological conditions in fish and pollution in the aquatic environment: A review.” *Veterinarni Medicina*, *61*(3), 123–132.

[39] Huntingford, F. A., Adams, C., Braithwaite, V. A., Kadri, S., Pottinger, T. G., Sandøe, P., & Turnbull, J. F. “Current issues in fish welfare.” *Journal of Fish Biology*, *68*(2), 332–372.

[40] Alex, J. N., & Thomas, J. K. (2011). “Effects of the organophosphorous methyl parathion on the branchial epithelium of a freshwater fish *Metynnis roosevelti (anabas tesudineus*: Bloch).” *Advances in Applied Science Research*, *2*(5), 167–172. 2011.

[41] Maharajan, A., Kitto, M. R., Paruruckumani, P. S., & Ganapiriya, V. “Histopathology biomarker responses in Asian sea bass, *Lates calcarifer* (Bloch) exposed to copper.” *The Journal of Basic & Applied Zoology*, *77*, 21–30.

[42] Hassaninezhad, L., Safahieh, A. R., Salamat, N., Savari, A., & Majd, N. E. “Assessment of gill pathological responses in the tropical fish yellowfin seabream of the Persian Gulf under mercury exposure.” *Toxicology Reports*, *1*, 621–628.

[43] Reddy, P., and Rawat, S. “Assessment of aquatic pollution using histopathology in fish as a protocol.” International Research Journal of Environment Sciences, 2, 79–82. 2013.

[44] Ruiz-Picos, R., & López-López, E. “Gill and Liver Histopathology in *Goodea atripinnis* Jordan, Related to Oxidative Stress in Yuriria Lake, Mexico.” *International Journal of Morphology*, *30*(3), 1139–1149.