International Journal of Fisheries and Aquatic Studies 2023; 11(2): 01-07

E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 76.37
(GIF) Impact Factor: 0.549
IJFAS 2023; 11(2): 01-07

www.fisheriesjournal.com
Received: 02-01-2023
Accepted: 05-02-2023

FJ Charo
University of Nairobi, Department of Veterinary Pathology, Microbiology and Parasitology, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

PG Mbuthia
University of Nairobi, Department of Veterinary Pathology, Microbiology and Parasitology, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

LC Bebora
University of Nairobi, Department of Veterinary Pathology, Microbiology and Parasitology, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

JM Nguta
University of Nairobi, Department of Public Health, Pharmacology and Toxicology P.O. BOX 29053-00625, Kangemi, Nairobi, Kenya

Corresponding Author:
FJ Charo
University of Nairobi, Department of Veterinary Pathology, Microbiology and Parasitology, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

Influence of aquaculture management practices and water quality on bacterial occurrence in fish culture units in Kenya

FJ Charo, PG Mbuthia, LC Bebora and JM Nguta

DOI: https://doi.org/10.22271/fish.2023.v11.i2a.2782

Abstract
Aquaculture management practices and water quality parameters influence bacterial occurrence in fish farms. This study aimed to identify the water quality parameters and aquaculture practices that cause bacterial occurrence in fish culture units in Machakos and Nyandarua counties. A cross-sectional study involved administering questionnaires to 46 randomly selected fish farmers and sampling water quality from fifteen selected fish farms from the two counties. The physico- chemical parameters collected and analyzed included; Temperature, turbidity, pH, organic matter content and dissolved oxygen levels in the fifteen selected farms. According to the findings, 45% of farmers in Nyandarua and 65% in Machakos use home-made feeds. All farmers in Nyandarua and 96% of farmers in Machakos use untreated pond water sources. Six heavy metals were detected from the water samples; Manganese, Iron, Calcium, Magnesium, Sodium and Potassium. Eight of the 15 sampled ponds had Manganese levels exceeding tolerable level of 0.05mg/L. Nine of the 15 ponds had Iron levels above the optimum of 0.3 mg/L. Fourteen of the 15 ponds had Magnesium levels below 75mg/L while 13 of the 15 ponds had Calcium levels below 75 mg/L. Only one of the 15 ponds had sodium levels below 1mg/L while four out of the 15 ponds had potassium levels below 1 mg/L. Bacteria genera isolated included *Acinetobacter, Aeromonas, Enterococcus, Micrococcus, Pseudomonas, Bacillus, Flavobacterium, Enterobacter, Escherichia, Hafnia, Kurthia, Rhodococcus, Citrobacter, Exiguobacterium, Pseudarthrobacter* and *Lysinibacillus*. The study reveals less compliance with biosecurity measures and good management practices for rearing fish in both counties which may result in high risk of heavy metal contamination. As a result, there is need for policy makers at national and county government levels to address these inadequacies through education and capacity building to enhance fish production.

Keywords: Aquaculture management, bacterial infection, cross-sectional field survey and water environment

Introduction
Aquaculture is a rapidly expanding food production sector globally (FAO, 2016) [11]. Fish farming in Kenya is mainly done under extensive, semi- intensive and intensive systems. Farmers practice either monoculture or polyculture using earthen ponds, liner ponds, concrete ponds, indoor or outdoor fish tanks or recirculatory aquaculture systems. Most production targets the food market although ornamental fish production is also gaining popularity (KeFS, 2020) [18]. Aquaculture management practices and water quality conditions directly influence occurrence of bacteria in fish farms (Romero *et al*., 2012) [25]. Different fish species have varying levels of tolerance to various water quality parameters. Thus, water quality parameters such as temperature, pH, turbidity, dissolved oxygen levels, nitrites, ammonia, hydrogen sulphide, and heavy metals among others must be regularly monitored and maintained at optimum levels for the different fish species to achieve a stable water environment that inhibits pathogenic bacterial occurrence (Jacob and Chenia, 2007) [15]. Variations in aquatic environments including physical, chemical and biological water quality parameters further stress aquatic organisms; weakening their immunity and thus increasing the likelihood of bacterial infection in fish (Ikeogu, 2010) [14]. Similarly, poor aquaculture management practices such as overstocking, use of excess organic manure for pond fertilization, lack of biosecurity measures in fish farms, use of contaminated feeds, infected

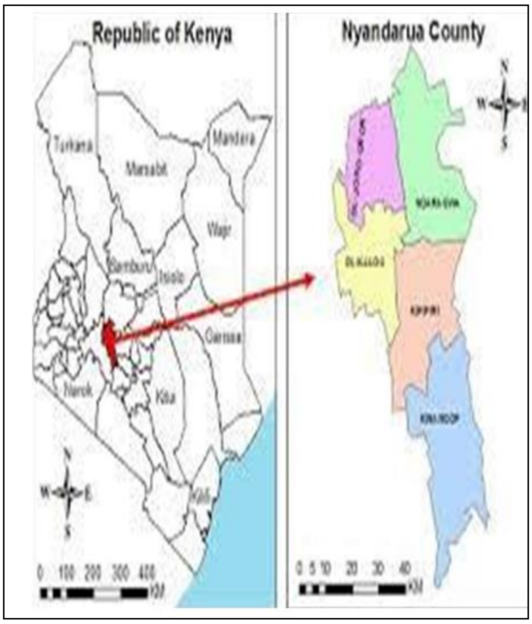
fingerlings, untreated water sources and poor pond water management among other issues create a fertile ground for bacterial growth and multiplication in fish farms (Hasan *et al*., 2013) [12]. Bacteria in fish farms can potentially cause diseases in fish, which is detrimental to the successful and profitable aquaculture production (Hasan *et al*., 2013) [12]. Some bacteria are zoonotic and cause human illnesses after consuming contaminated raw or undercooked fish (Janda and Abbort, 2010) [16]. Therefore, knowledge of the best aquaculture practices is critical for successful fish production. This study investigated aquaculture management practices and water quality parameters that can cause bacterial occurrence in cultured fish and pond water in Machakos and Nyandarua counties in Kenya. The goal of the study is to fill knowledge gaps and practical inadequacies in proper aquaculture management practices among fish farmers such as lack of pond disinfection, untreated water sources, sharing of fish nets, lack of footbath at farm entrances, isolation ponds for sick fish, livestock farming around ponds, pond fertilization using animal manure and access to ponds by a predator so as to correct and improve fish production through extension services and capacity building.

Materials and Methods

Study Area and Research Design

The study was conducted in Machakos and Nyandarua counties, in Kenya. Machakos lies between latitude 0o 45’ South to 0o 31’ South and longitude 36 o 45’ East and 37 o45’ East while Nyandarua lies between latitude 0o 32’59.99 North and longitude 36o 36’59.99 East. A cross- sectional study involved development and administration of structured questionnaire to evaluate fish farming practices that can cause bacterial occurrence in fish farms. The pond water was sampled and evaluated for pollutants and status of physico-chemical parameters from selected farms in sub counties in Nyandarua and Machakos, Kenya.

Machakos county



Nyandarua county map

Sample size determination

Nyandarua County had a total of 30 active fish farms across all five sub counties namely Olkaou (9 farms), Ndaragwa (7 farms), Kipipiri (6 farms) Oljororok (2 farms) and Kinangop (6 farms) while Machakos County had 52 active fish farms across four selected sub-counties including Mavoko (16 farms), Machakos Town (15 farms), Kangundo (11 farms) and Matungulu (10 farms). The four subcounties in Machakos county were purposefully selected because of their proximity to the investigation laboratories in the University of Nairobi.

Eelection of farms for pond water sample collection and questionnaire administration

A total of 46 farms comprising 20 from Nyandarua and 26 from Machakos counties were randomly selected for questionnaire administration (Cochran, 2007). A systematic random sampling was done where a sample size *n* was calculated from the sampling frame *x* by selecting the *(x/n)th* individual.

Machakos n =52/2 =26
Nyandarua n= 30/2 = 15
n is the sample size
x is the sampling frame.
(x/n) th is every second (2) farm in the sampling frame

The selected farms included both monoculture and polyculture farms which were either earthen, liner or concrete. They were practicing either extensive, semi-intensive and intensive fish farming systems including recirculatory aquaculture systems. The main cultured fish species in both counties were Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus).* Some farmers in Nyandarua also cultured Rainbow trout (*Oncorhynchus mykiss).* Administration of questionnaire was carried out between February and March 2021 through face-to-face structured interviews. The questionnaire evaluated risky aquaculture practices in fish farms likely to cause infectious diseases. Specifically, it assessed the source of fish feeds, the source of pond water, sources of fingerlings, type of ponds, type of farming systems, type of fish cultured, frequency of water change, pond fertilization methods, pond disinfection, stocking density, feed shortage, water shortage, crop and livestock farming around ponds. The questionnaire also assessed human settlement around ponds, access of ponds by predators, floods and surface run-off through ponds, footbath at farm entrance, sharing of fish nets, disinfection of fish nets after use, incidences of diseases in the farms and treatment of fish diseases.

Out of the 46 farms selected for questionnaire administration, 15 farms were selected for sampling for fish and pond water quality parameters. The 15 fish farms were selected for pond water sampling using a formula described by Louangrath, (2017) [29]. The formula used for selection assumed a confidence interval of 95% and a maximum variability of P=0.05 (Louangrath, 2017) [29]. These fish farms consisted of eight farms from Machakos and seven farms from Nyandarua Counties. In Machakos, four farms were selected from the urban sub counties of Machakos town and Mavoko and another four from the peri-urban subcounties of Kangundo and Matungulu. In Nyandarua, water sample were collected from one farm in Ndaragwa and from two farms each in Olkalou, Kipipiri and Kinangop.

Sample size determination

Fish and water sample size was determined statistically using the formula:

$$n= \frac{z^2\, p(1-p)}{d^2}$$

(Naing *et al*., 2006)) where n was the sample size, z was the z statistic at 95% confidence level, p was the expected prevalence of bacterial pathogens which was assumed to be 50% while d was the precision which was 0.05. This gave a sample size of 384. Due to resource constraints 330 representative samples (300 fish tissue and 30 water samples) were collected.

Two sets of water samples were collected. One set using two-liter capacity plastic containers submerged 20 cm deep before 10:00 hours, from each of the selected ponds. The second set was collected using a 50 ml universal bottle also submerged 20 cm deep from each of the selected ponds. Overall, 30 water samples were collected. The first set of 15 water samples were labeled, packed in a cooler box with ice and taken to the Government Chemist for analysis of nitrites, nitrates, ammonia, hydrogen sulfide, chlorides, fluorides, phosphates and silicates. Temperature, turbidity, pH, organic matter content and dissolved oxygen levels were also measured. Presence of heavy metals such as Calcium, Sodium, Potassium, Iron, Magnesium and Manganese levels were also determined. The second set of 15 water samples was collected using sterile universal bottles alongside fish samples for bacterial isolation and identification at the University of Nairobi's Department of Veterinary Pathology, Microbiology and Parasitology laboratories.

Ethical clearance

The study was approved by the University of Nairobi's Faculty of Veterinary Medicine, Biosafety, Animal Use, and Ethics Committee (Reference Number FVM BAUEC/2020/273) and licensed by Kenya's National Council for Science, Technology, and Innovation (Reference Number 842968).

Data processing and analyses

Data collected was cleaned and entered in an Excel spreadsheet. Statistical analysis was done using descriptive measures such as frequencies, percentages, tabulations, and graphs. R-Console version 3.6,3 was used for inferential statistics.

Results and Discussion

Aquaculture practices in Machakos and Nyandarua counties

Presence of biosecurity measures in fish farms

There was no single farm in Nyandarua County that had a footbath at the farm entrance for human and vehicle traffic disinfection before entering the farm. Only 7.6% of farms in Machakos County had with a footbath. Fishing nets were not disinfected in both counties, which could lead to transmission of pathogens between farms and ponds. This increased the risk of pathogen introduction into the farm from both human and vehicle traffic. According to Blanco *et al*. (2000) [4], any equipment used in a fish pond must be thoroughly disinfected before being used in another pond. Few fish ponds were disinfected before stocking or restocking, with Nyandarua at 5% and Machakos at 12% (Table I). The majority of farmers did not change pond water during a production cycle, resulting in accumulation of organic matter which contributes to occurrence of bacteria (Blanco *et al*., 2000; Ngwili *et al*., 2015) [4, 24].

Table I: Aquaculture management practices in Nyandarua and Machakos counties

Farming practice	Nyandarua (N=20) (%)	Machakos (N=26) (%)
Accessibility to ponds by predators	85	92
Crop/livestock farming around pond	85	58
Feed shortage	45	69
Use of home-made feeds	45	65
Pond fertilization	25	58
Sharing of fish nets among farmers	65	38
Earthen ponds	45	27
History of disease in farm	35	23.1
Pond disinfection before stocking or restocking	5	12
Footbath at farm entrance	0	7.6
Weighing of fish before feeding	10	3.8

Student t-test showed there was no significant differences in aquaculture practices between Nyandarua and Machakos counties ($p > 0.05$).

Based on personal observations, there were no isolation ponds for sick fish nor were there disposal units for dead fish in both counties. Biosecurity measures and pond management practices were unfamiliar to fish farmers in Nyandarua and Machakos. This was consistent with the findings of Chenyambuga *et al.* (2014) [6], who reported similar challenges among farmers in Tanzania's Mvomero and Mbarali districts.

Fish pond environment

Farmers in both counties cultivated crops or raised livestock near the pond areas; with 85% in Nyandarua and 58% in Machakos. Pond fertilization using animal manure was also rampant among the farmers interviewed, with Machakos having 58% and Nyandarua having 25% of their ponds fertilized with livestock manure. The use of organic manure (dung from cow, sheep and poultry) increases the risk of introduction of pathogens into the pond water system. These findings agreed with those of Wanja *et al*. (2020) [27], who reported use of raw livestock manure in fish ponds as a potential risk factor for fish mortality and acquisition of infectious pathogens in the pond environment in Kirinyaga County. Another key finding was the access of pond area by predators mainly piscivorous birds and mammals. Up to 92% and 85% of pond area in Machakos and Nyandarua counties respectively were not adequately protected to prevent access by predatory birds (Table I). Other mammals like otters, dogs, livestock, and humans could access 80% of the pond area in both counties. Predators contaminate the pond environment with parasites and pathogens. Murugami *et al.* (2018) [22] reported that bird migration poses a risk of spreading parasites and other disease-causing pathogens in fish farms in Kirinyaga County. However, in contrast to Murugami *et al.* (2018) [22] who reported helminths parasites were spread by predatory birds, this study showed bacteria that can possibly be spread by piscivorous birds and other mammalian predators like livestock, dogs, otters, and humans that can access the pond area.

Sources of farm inputs

Due to the scarcity and high cost of commercial fish feeds on the market, most farmers in both counties used home-made feeds. Home-made feeds were used by 65% and 45% of the farms sampled in Machakos and Nyandarua respectively. Feed shortage was reported in 69% of farms in Machakos and 45% of farms in Nyandarua (Table I). The use of home-made feeds coupled with incessant feed shortages exposes fish to contaminated low quality feeds making them vulnerable to bacterial infections. Keziah *et al.* (2017) [19] reported similar findings in Kiambu County, as did Wanja *et al*. (2020) [27] in Kirinyaga County. This present study further showed lack of knowledge among farmers on the amount of feeds given to the fish since only 3.8% of interviewed farmers in Machakos and 10% in Nyandarua reportedly weighed fish before feeding. The sources of water for the pond were not of good quality either with Nyandarua using surface run-off water in 40% of the farms and Machakos using borehole water in 38% of farms. Surface water run-off is a potential source of pathogens to cultured fish and aquatic environment (Henrickson *et al*., 2001) [13]. Another source of water were rivers at 23% in Machakos and 25% in Nyandarua, respectively. River water source can introduce micro-organisms which are potential pathogens for fish (Blanco *et al*., 2010) [4]. Most farmers did not treat the water before use therefore creating an opportunity for introduction of potential pathogens into the culture system. Such an aquatic environment tends to increase bacterial presence in the cultured fish and the source pond water (Sanz-Lazaro and Sanchez-Jerez, 2017) [26]. Fingerlings were sourced mostly from private hatcheries with Nyandarua having 65% of the farms sourcing fingerlings from private hatcheries while 62% of farmers sourced fingerlings from private hatcheries in Machakos. Only 15% of farmers interviewed bought fingerlings from Government hatcheries in both counties (Table I). About 12% of farmers in Machakos sourced fingerlings from wild water bodies such as rivers, lakes and streams. Fingerlings sourced from wild waters and other farmers whose quality may not be verified and certified can lead to transmission of pathogens from the wild to the farmed fish ponds or from one farm to the other.

Pond types and pond water management

Most farmers in Nyandarua County had earthen ponds (45%); followed by liner ponds 35% and concrete ponds 20%. Liner ponds were the most common in Machakos, accounting for 54%, followed by earthen ponds (27%) and concrete ponds (19%). Overall, earthen and liner ponds were the most commonly used ponds in both counties. Earthen ponds are more difficult to clean and disinfect, prone to vegetation growth, snails and piscivorous birds invasion (Murugami *et al*., 2018) [22], all of which increase the likelihood of bacterial occurrence in these types of fish ponds. In terms of pond water management, 65% of farms in Nyandarua County either changed water after six months, did top up only or never changed pond water, whereas 50% of farmers in Machakos did the same (Table 1.). This resulted in poor pond water quality characterized by accumulation of organic matter, fish waste, polluted water and low dissolved oxygen levels.

Status of diseases in fish farms

Thirty five percent of farms in Nyandarua reported to have experienced fish diseases while Machakos had 23.1% of their farms reporting fish diseases. Twenty percent of farms in Nyandarua County had recorded fish deaths due to fish diseases while Machakos had 11.5% of such records (Table I). Main disease symptoms reported by farmers were reduced feeding, abnormal swimming movements, skin color change, swollen abdomen and popping eyes. Poor fish farming practices have a direct influence in the presence of infectious bacteria that might have caused the reported diseases in the fish farms (Hasan *et al*., 2013) [12]. Water pollutants and parameters status in Machakos and Nyandarua counties

Water temperature

Temperature tolerance varies between fish species. Tilapia and catfish thrive in temperatures ranging from 20 to 35 °C (El-Sayed, 2008) [10], whereas rainbow trout thrive in temperatures ranging from 15 to 20 °C (Molony, 2001) [21]. Because fish are cold blooded, the temperature of the surrounding water affects their body temperature, growth rate, feed consumption, feed conversion, and other body functions. Pond water temperatures in Nyandarua fish farms averaged 19 °C, which was slightly lower than the optimum levels for growth of catfish and Nile tilapia. As a result of cold temperature stress, catfish and Nile tilapia cultured in lower temperature farms (N5 and N6) in Nyandarua County were predisposed to infection by psychrophilic bacteria such as *Aeromonas hydrophila* and *pseudomonas* species. In Machakos, the average pond water temperature was 22.1 °C, which was suitable for catfish and Nile tilapia culture as observed in farms M1, M4, M5 and M6. These warm temperatures were favorable for growth of mesophilic bacteria such as *Escherichia coli*, *Aeromonas*, *Pseudomonas* and *Enterococcus* species, among others (Tables II and III). Due to the warm water temperature, farms in Machakos harbored four more bacterial genera that were not isolated in the cold climate farms of Nyandarua. These four genera were *Exiguobacterium*, *Pseudarthrobacter*, *Lysinibacillus* and *Rhodococcus*.

Table 2: Water temperature (OC) and Physico-chemical (mg/l) parameters that influence fish health in Nyandarua

	N1 Farm	N2 Farm	N3 Farm	N4 Farm	N5 Farm	N6 Farm	N7 Farm	Optimum Level
Temperature	18	20	23	23.7	15.7	18.3	20.7	20-35
Turbidity	4.3	85	25	170	340	200	120	0-25

Nitrites	0.003	0.054	0.162	0.814	0,86	0.74	1.005	0 – 0.2
Hydrogen sulfide	183	9.6	276	230	236	280	350	0
Chlorides	10	7.5	130	40	15	17.5	10	0
Iron	0.24	4.95	1.52	4.96	10.9	3.19	3.76	0 - 3.0
Manganes	0.054	0.86	0.076	0.207	3.67	0.69	0.31	0 – 0.05
Calcium	8.0	6.0	12	8.0	12	12	40	75 - 200
Magnesium	12	9.6	14.4	19.2	16.8	6.0	13.2	75 - 200
Sodium	5.38	4.68	56.8	16.8	8.3	4.6	4.8	1 - 2
Potassium	1.655	0.3	4.405	8.707	8.106	4.8	2.4	1 – 2

Table 3: water temperature (OC) and Physico-chemical (mg/l) parameters that influence fish health in Machakos

	M1 Farm	**M2 Farm**	**M3 Farm**	**M4 Farm**	**M5 Farm**	**M6 Farm**	**M7 Farm**	**M8 Farm**	**Optimum levels**
Temperature	23	20.8	21.9	22.6	22.2	22.3	21.4	21.9	20 - 35
Turbidity	5.7	6.9	120	140	7.3	2.3	24	31	0 - 25
Nitrites	0.024	0.51	0.017	nil	0.97	0.05	0.044	0.157	0 – 0.2
Hydrogen Sulfide	16	4	nil	2.0	20	20	66	40	**0**
Chlorides	70	450	100	470	nil	25	10	15	0
Iron	0.07	Nil	0.05	0.24	nil	0.51	1.03	1.26	0 - 0.3
Manganese	0.007	0.09	0.001	0.03	0.005	0.052	0.47	0.39	0 - 0.05
Calcium	24	120	8.0	20	6.0	80	nil	nil	75 - 200
Magnesium	26.4	132	19.2	31.2	4.8	36	nil	nil	75 - 200
Sodium	54.7	Nil	171.45	779	23.11	47.8	0.51	0.46	1 - 2
Potassium	nil	Nil	9.37	103.62	2.88	nil	0.29	nil	1 - 2

Water turbidity

In both counties, most of the ponds had water with very high turbidity. Water in 71% of the ponds in Nyandarua and 37.5% in Machakos had a turbidity of more than 25mg/l. Most ponds had increased organic matter accumulation, sediments from surface water run-off into ponds, and a low frequency of pond water change, resulting in high pond water turbidity. High pond water turbidities were observed in eight farms, namely M3, M4, M8, N2, N4, N5, N6 and N7 which caused occurrence of bacteria in most of these ponds. This was consistent with the findings of Martin-Carnahan and Joseph (2015) [20] who reported occurrence of *Aeromonas* species in pond sediments (Tables I and III). In Machakos County, the high-water turbidity ponds were found in the urban sub counties of Machakos and Mavoko Towns, and these ponds contained more bacteria genera that were not found in the low turbidity ponds in peri-urban subcounties of Kangundo and Matungulu. These bacteria genera included *Flavobacterium, Micrococcus, Enterococcus, Rhodococcus, Escherichia, Exiguoacterium* and *Lysinibacillus*.

Nitrites levels

In Nyandarua, four (N4, N5, N6 and N7) out of the seven farms sampled had nitrites levels of above 0.2mg/L but less than 2mg/L in their ponds; whereas in Machakos, two (M2 and M5) out of the eight sampled farms had nitrites levels of above 0.2mg/L but less than 1mg/L in their ponds. Tolerable range is 0 - 0.2mg/L (Bhartnagar and Devi, 2013) [3]. Amounts greater than 0.5mg/L will cause hypoxia due to entrance of nitrite into the bloodstream through the gills and combination with hemoglobin to form methemo-globin. This results in the blood turning to chocolate-brown color and the oxygen carrying capacity of the blood being horrendously reduced. The gills turn brown from their normal bright red appearance. Affected fish suffocate and gasping is observed despite presence of adequate oxygen concentration in water. As a result, there is damage of liver, gills and blood cells. This condition is often referred to as brown blood disease. It weakens the fish immune system thus predisposing them to bacterial infections such as *Aeromonas* and Columnaris bacterial infections (Tables II and III).

Hydrogen sulfide levels

Hydrogen sulfide was detected in pond water of all the seven farms sampled in Nyandarua County while in Machakos, seven out of the eight sampled farms had hydrogen sulfide traces. In culture ponds, H2S is liberated as result of decomposition of food and organic matter (Boyd, 1979) [5]. Hydrogen sulfide levels in pond water should be nil (Bhartner and Devi, 2013) [3], concentration as low as 0.1mg/L is lethal to fish. It can cause cyanotic effect to the gills, spleen and liver damage. This weakens the fish immune system and predisposes it to bacterial infections.

Chlorides levels

Levels of chloride were elevated in 93% of the sampled ponds in both counties. Chloride concentrations of as little as 3 ppm kill most fish rapidly (Andres and Sandra, 2020) [1]. High chloride concentration in freshwater harm aquatic organisms by interfering with osmoregulation. Elevated chloride levels inhibit aquatic plant growth, impair reproduction, and reduce the diversity of aquatic organisms. Use of livestock manure, fertilizers and wastewater in fish ponds are potential sources of chlorides.

Heavy metals levels

Six metals were detected in the pond water samples namely sodium, potassium, calcium, magnesium, iron and manganese. This agrees with the findings of Yabe *et al.* (2010) [28] who reported pollution of African aquatic environments with metals such as iron, manganese, lead, mercury, copper, zinc, cobalt and arsenic among others because of expansions in agricultural and industrial activities. All metals are toxic to aquatic animals if the exposure level is sufficiently high to exceed the tolerable levels. Similarly, deficiencies in essential mineral metal elements can also affect fish health. Sodium salts in freshwater ponds is important in maintaining osmotic balance. Low sodium levels below 1mg/mL as observed in M2 farm (Table III) may cause dropsy in fish as water will diffuse into the fish. Freshwater fish grow well at potassium and sodium concentrations of between 1–2 mg/L (Ekrem and Asli, 2018) [9]. Adding sodium and potassium to fish feeds improves fish growth rate and feed efficiency. Lack of potassium as observed in M1, M2, M6 and M8 farms (Table III) will stress and slow fish growth therefore predispose them to bacterial infection. Calcium and magnesium are essential metal elements. Calcium helps in blood clotting, muscle contraction and bone formation in fish. Low calcium and magnesium levels below 75mg/L in water as observed in farms M1, M3, M4, M5, M6, M7, M8, N1, N2, N3, N4, N5, N6 and N7 (Tables II and III) are unfavorable for good fish health. Iron is a constituent of hemoglobin. Iron level above 0.3mg/L and Manganese levels exceeding 0.05 mg/l will cause impaired functions of the fish gill epithelium (Dolci *et al*., 2017) [8]. Excess iron in fish culture ponds forms iron hydroxide that can clog the gills and kill the fish (Benjamin and Richard, 2011) [2]. Excess iron levels were observed in M6, M7, M8, N2, N3, N4, N5, N6 and N7 farms (Tables II and III) while excess manganese levels were detected in N2, N3, N4, N5, N6, N7, M2 and M8 farms (Tables II and III).

Bacterial isolates

Sixteen bacterial genera were isolated from the water and fish samples collected from the 15 selected farms and analyzed and the laboratories in the department of Veterinary Pathology, Microbiology and Parasitology, University of Nairobi. These bacterial genera included *Aeromonas, Pseudomonas, Flavobacterium, Bacillus, Acinetobacter, Micrococcus, Enterococcus, Enterobacter, Citrobacter, Rhodococcus, Escherichia, Kurthia, Hafnia, Exiguobacterium.*

Pseudarthrobacter and *Lysinibacillus*. Most of these are conditional fish pathogens that can cause massive losses in aquaculture. Some of the bacteria isolated and identified are zoonotic hence are of public health significance. These included *Aeromonas hydrophila and Aeromonas veronii, Citrobacter freundii*, *Enterobacter cloaca,Hafnia alvei ,Escherichia coli , Bacillus cereus and Pseudomonas putida.*

Conclusions and Recommendations.

Poor aquaculture practices such as pond fertilization with animal manure, sharing of fish nets, lack of pond disinfection, use of contaminated fish feeds, use of untreated water sources, unproven sources of fingerlings and access of ponds by predators among others may have contributed to the presence of bacteria in fish and pond water sources. These bacteria are conditional fish pathogens and some are zoonotic with potential to cause human illnesses. Warm water temperatures of Machakos county favored multiplication of more bacteria compared to cold temperature areas of Nyandarua County. High turbidity ponds in urban areas had more bacterial isolates compared to low water turbidity ponds in peri-urban areas of Machakos County. The heavy metals and anions detected posed a risk of toxicity and immune suppression to the fish and also a public health hazard to fish consumers. The study recommends awareness creation and capacity building among fish farmers in both counties through extension services on better aquaculture management practices and optimal water quality parameters.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

Kenya Climate Smart Agricultural project (KCSAP) for funding the study and the Veterinary Pathology, Parasitology and Microbiology department, University of Nairobi for technical support. Special thanks to the directorates of veterinary and fisheries in both Nyandarua and Machakos for giving authorities for data collection from the two counties. Appreciation to the fish farmers for giving information that enhanced success of the study.

References

1. Andres HA, Sandra EB. Coastal and Deep Ocean Pollution, CRC press; c2020.
2. Benjamin JS, Ricard DH. Physiological effects of nanoparticles on fish; A comparison of nanometals versus metal ions. Environment international. 2011;37(6):1083-1097.
3. Bhatnagar A, Devi P. Water quality guidelines for the management of pond fish culture. International Journal of Environmental Sciences. 2013;3(6):1980–2009.
4. Blanco MM, Gibello A, Fernandez-Garayzabal JF. Influence of fish health management; Bases, procedures and economic implications. Cahier Options Mediterraneennes. 2000;51:45-9.
5. Boyd C, Tucker CS. Water quality requirements. In Pond Aquaculture Water Quality Management, 1998, 87-153.
6. Chenyambuga SW, Mwandya A, Lamtane HA, Madalla NA. Productivity and marketing of Nile tilapia (*Oreochromis niloticus*) cultured in ponds of small-scale farmers in Mvomero and Mbarali districts, Tanzania. Livestock Research for Rural Development. 2014;26(3):3-12.
7. Cochran WG. Sampling techniques. John Wiley and Sons; 2007.
8. Dolci GS, Dias VT, Roversi KR, Roversi CS, Pase HJ, Segat AM, *et al*. Moderate hypoxia is able to minimize the manganese-induced toxicity in tissues of silver catfish. Ecotoxicology and environmental safety. 2013;91:103-109.
9. Ekrem M, Asli K. Assessment of physico-chemical parameters and heavy metal pollution in Celtek Pond water. NISCAIR-CSIR, India; c2018.
10. El-sayed AF, Kawanna M. Optimum water temperature boosts the growth performance of Nile tilapia fry reared in recycling system. Aquaculture Research. 2008;39(6):670
11. Food and Agriculture Organization. The State of World Fisheries and Aquaculture. Contributing to food security and nutrition for all; c2016.
12. Hasan MM, Faruk MAR, Anka IZ, Azad MAK. Investigation on fish health and diseases in rural pond aquaculture in three districts of Bangladesh. Journal of Bangladesh Agricultural University. 2013;11(2):377-384
13. Henrickson S, Epstein PR, Ford T, Wong T, Allen P. Marine swimming- Related illness; implications for Monitoring and Environmental Policy; c2001.
14. Ikeogu FC, Nsofor CI, Ikpeze OO. A review of risk factors for fish diseases in aquatic environments. Proceedings of the 6th National Conference of the Society for Occupational Safety and Environmental Health (SOSEH), 2010, 199-204
15. Jacobs L, Chenia HY. Characterization of integrons and tetracycline resistance determinants in *Aeromonas* spp. Isolated from South African aquaculture systems. International journal of Food Microbology. 2007;114(3):295-306
16. Janda JM, Abbort SL. The genus *Aeromonas*: taxonomy,

pathogenecity and infection. Clin. Microbiology. Rev. 2010;23(1):35-73.
17. Khalef WF, Abedali ST, Faris HN. Assessment of the water quality of the Hafar river using the water quality index (Canadian model). Int. J Geogr. Geol. Environ 2022;4(1):13-15.
18. Kenya Fisheries Services. State of Aquaculture report in Kenya; c2020.
19. Kezia WN. Prevalence of parasitic infections in farmed nile tilapia and factors associated with transmission in Kiambu county, Kenya. (Masters Dissertation, University of Nairobi); c2017.
20. Martin-Carnahan A, Joseph SW. Aeromonas. Bergey's Manual of Systematics of Archaea and Bacteria, 2015, 1-44
21. Molony B. Environmental requirements and tolerance of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Department of Fisheries, Government of Western Australia; c2001.
22. Murugami JW, Waruiru RM, Mbuthia PG, Maina KW, Thaiya AG, Mavuti SK, *et al*. Helminths parasites of farmed fish and water birds in Kirinyaga county, Kenya. International Journal of Fisheries and aquatic studies. 2018;6(3):6-12
23. Naing L, Winn T, Rusli BN. Practical issues in calculating the sample size for prevalence studies. Archives of orofacial science. 2006;1:9-14
24. Ngwili NM. Characterization of fish farming systems in Kiambu and Machakos counties, Kenya. Doctoral Dissertation, University of Nairobi); c2014.
25. Romero J, Feijoo CG, Navarrete. Antibiotics in aquaculture-use,abuse and alternatives, Health and environment in aquaculture. 2012, 159-198.
26. Sanz-Lazaro C, Sanchez-Jerez P. Mussels do not directly assimilate fish farm wastes:shifting the rationale of integrated multi-trophic aquaculture to a broader scale. Journal of Environmental Management. 2017;201:82-88.
27. Wanja DW, Mbuthia PG, Waruiru RM, Mwadime JM, Bebora LC, Nyaga PN, *et al*. Fish husbandry practices and water quality in central Kenya: potential risk factors for fish mortality and infectious diseases. Veterinary Medicine International; c2020.
28. Yabe J, Ishizuka M, Umemura T. Current levels of heavy metal pollution in Africa. Journal of Veterinary Medical Science. 2010;72(10):1257-1263.
29. Louangrath PI. Minimum sample size method based on survey scales. Int. J. Res. Methodol. Soc. Sci. 2017 Jul;3:45.