



Temporal patterns of physicochemical and bacteria profiles of static aquaculture systems: insights into health hazards for fish and the public

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ABSTRACT

Knowledge on water quality in static aquaculture systems is crucial to gain understanding of health threats to fish or aquaculture personnel. In the present study, we investigated the temporal profiles of the bacteriological profiles and physicochemical status of static water aquaculture systems (earthen ponds and concrete tanks). All physicochemical parameters measured were within the optimum recommendation. Following microbial analyses in earthen pond water, the TVC and TCC showed temporal variations with concentration increasing with sampling time, however, FCC fluctuated, and 8 bacteria groups were isolated from both rearing enclosures. In which Gram (-) bacteria showed dominance, with 5 Gram negative (*Escherichia coli*, *Proteus spp*, *Serratia spp*, *Enterobacter spp* and *Pseudomonas spp*) and 3 Gram positive (*Staphylococcus spp*, *Streptococcus spp*, and *Bacillus spp*) encountered. From earthen pond water, the following microbial occurrences were reported: *Staphylococcus spp* (20%), *Streptococcus spp* (12%) *Proteus spp* (8%) *Enterobacter spp* (20%) *Serratia spp* (16%), *Bacillus spp* (9%), *Escherichia coli* (8%), *Pseudomonas spp* (7%). While *Staphylococcus spp* (18%), *Streptococcus spp* (16%), *Proteus spp* (8%), *Enterobacter spp* (22%), *Serratia spp* (8%), *Bacillus spp* (15%), *Escherichia coli* (8%), *Pseudomonas spp* (6%) occurred in concrete water. Taken together, although the physicochemical condition raised no well-fare concern, however, the bacteriological profile during this investigation showed potential health risk in static water aquaculture condition or to adjacent aquatic environment from end of production-discharge.

1. Introduction

Aquaculture is the fastest growing food sector in the world today, and it is an activity involving the captive production of aquatic resources at a density differing from what is found in the natural environment. The increasing demand for seafood products has intensified the stocking densities in the aquaculture system today. One implication of this is the increasing crowding, possibly subjecting fish to stressor experience, and consequently, increased infection rate due to suppressed immune responses. One single most significant factor devastating the aquaculture industries is disease. For example, in the shellfish industry, an estimate revealed US\$8–15 billion shellfish value was lost globally to a single disease agent, white spot syndrome virus (WSSV) [27]. Likewise global losses associated with other OIE listed viruses were documented: infectious hypodermal and hematopoietic virus, IHHV (US\$1billion); Yellow head virus (YHV), US\$0.5billion; Taura syndrome virus, (TSV), US\$3billion [41]. Yet, unlike other livestock production, the aquatic environment presents limitations to biosecurity. That is, due to the open nature of this environment— sometimes with exception of closed

systems, such as recirculatory aquaculture— total exclusion of pathogens may be impractical [21,23]. And in the presence of stressor(s), the health of the stock may be under jeopardy [15] which can devastate the economical, ethical and environmental sustainability of aquaculture. For instance, in Ecuador, loss due to WSSV outbreaks was around 63,000mt valued at US\$280.5 million, and it was estimated that up to 23,000people had been laid off [3].

In addition to this concern, aquatic environments have been implicated to represent reservoirs of pathogenic organisms which may pose risks to human health [14,24]. A good indication of presence of pathogenic bacteria are common attributes to fecal coliform bacteria, for example, the *Escherichia coli* and enterococci [43]. Moreover, since pathogenic colonization of aquatic organisms can depend on concentration of pathogens [14], of particular concern is the aquaculture practicing zero-water exchange. In which present pathogenic challenge may increase to the level capable of overwhelming the stock defense system [6] thereby leading to the establishment of pathogens. Subsequently, this water is discharged to the surrounding environment which further poses risk to the wild population or threats to human use [45]. In

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Nigeria, for instance, a majority of the aquaculture production is pond-based [1] and due to limited water supply, these aquaculture usually involve nearly/zero water exchange. According to a study in Nigeria, 35.7% surveyed farms practiced stagnant water aquaculture, with 48.2% practicing throughflow systems and only 16.1% adopting water recirculatory systems [17].

Several lines of evidence have demonstrated increased pathogens may pose risks to the surrounding environments [2,39]. For example, the probability of detecting pathogen environmental DNA was 2.72 times greater at active farms compared to inactive farms [39]. To the best of the authors' knowledge, the majority of studies have based their exploration on the microbial profiles and the antibiotic susceptibility tests (e.g., [18,30,31]) however disregarding the comparisons of sampling times and changes to bacteria profiles. Therefore, in order to gain insight into the health status of aquaculture settings practicing stagnant water aquaculture, this study set out to investigate the microbial profile, particularly bacteria, and quality of waters used for aquaculture in the study area. With consideration of temporal variations in bacteria concentration. The outcomes of which may serve to extrapolate conditions of other regions— especially those adopting similar management practices.

2. Materials and methods

2.1. Study area

The current investigation was conducted within the region of Kwara state, Nigeria, and is characterized with varieties of economic activities. Aquaculture operations is one major agricultural activity conducted in this area, with most adopting pond water aquaculture with some incorporating concrete culture during production stages. The most cultured species is the African catfish (*Clarias gariepinus*). Notably, the majority of aquaculture operations are aggregated into farm 'estates' with different people operating on the average 2 ponds/ individuals. That is, different 'estates' adopt similar management practices and are exposed to limited variation in environmental conditions. The names of these farm estates are kept anonymous to protect farm integrity. In total, 5 different farm estates were covered in the present study, and the regions fall within the western region of Kwara Province.

2.2. Sample collection and farm related data

Water samples were collected from five fish farms (two water holding facilities, earthen ponds and concrete tanks from each farm) using sterile bottles from below water level approximately 10–15 cm below the surface [30]. The water was transported to the Microbiology laboratory in the department of Microbiology, University of Ilorin in an ice-packed container for bacteriological analysis. Earthen ponds and concrete tanks water samples were collected from different fish farms in the study area at the different sampling time (3 days interval). Additional management related information about the ponds such as dimensions, culture duration, stocking number, feeding practice, source of water supply and length of use were obtained by interview. The maximum rearing duration range from 6 to 7 months in earthen ponds and 4–5 months in the concrete tanks. While farm B and C solely operate on borehole, farm A, D and E, are located near Asa-dam, Ilorin, they rely on dam water through direct pumping. Water topping is practiced by each farm to replenish water loss to evaporation and seepage, particularly in concrete tanks.

Though the earthen pond size were not measured due to dimension loss associated with wear and tear earthen pond dyke, however, the historical pond size obtained from farm managers ranges between 15 m × 10 m × 1.5 m to 25 m × 10 m × 1.5 m. While the typical concrete tank size obtained ranged from 5 m × 2.5 m × 1.2 m to 10 m × 5 m × 1.2 m. The average stocking number adopted in farm A, B, C, D and E range from 5000 to 10,000/earthen ponds, whereas the number of fish stock in concrete tanks range between 500–5000fish/concrete tank. Information

obtained on feeding practice include type of commercial feed, feeding strategy, feeding rate. In all farms investigated, feeding to satiation was the feeding strategy adopted using local made with crude protein content (42%), except farm B and C procuring foreign feed, such as Aller-Aqua, Coppens, or Skretting commercial feed products. All farm feed twice daily, 7–8 AM GMT and 6–7 PM GMT. No information was available on the food conversion efficiency, however, commercial feed used in farm B and C claimed expected FCR ranges between 1.2 and 1.5.

2.3. Determination of water quality parameters

The physical and chemical parameters of the pond water were measured within the holding time of each parameter following standard methods.

2.4. Determination of pH, temperature, electrical conductivity, dissolved oxygen (DO) and total dissolved solids (TDS), total nitrogen (TN), alkalinity and water hardness (WH)

Water temperature (°C), total dissolved solids (TDS, mg/l), pH, electrical conductivity (ms/cm) and alkalinity were measured in-situ using digital HANNA meter model HI 9813–5 between 8 and 11 GMT. Similarly, the Dissolved Oxygen was measured in-situ using Digital DO meter model JPB-607A Power:6 V. In the Industrial Chemistry Department, Total nitrogen determination was followed using UV spectrophotometric method as spelt out by Gross et al. [22], whereas measurement of water hardness followed standard complexometric titration using EDTA.

2.5. Bacteriological analysis

Sterilization of Material Used: the materials used for this study were sterilized by appropriate technique. All glass wares such as Petri dishes, conical flasks, test tubes, beakers, McCartney bottles, etc., were thoroughly washed and sterilized in the hot air oven at 160 °C for about 1 h. The media used for these were Nutrient Agar (NA), MacConkey Agar (MA) and Eosin Methylene Blue (EMB). 28 g, 48.5 g, and 37.5 g of NA, MA and EMB were weighed and suspended in 1 l of distilled water respectively. The mixture was then mixed properly and heated to dissolve the powder completely. After heating, the mouth of the flasks was plugged with cotton wool and wrapped with aluminum foil. The media were sterilized at 121 °C for about 15 min in autoclave and then allowed to cool for about 45 °C before pouring aseptically into the sterile Petri-dish.

Bacteriological procedures: serial dilution method was used for the enumeration of the bacterial count. 1 ml of each of the samples were transferred into 9 ml of sterile distilled water in the test tube. Serially, 1 ml was taken from the 10⁻¹ tube to another which makes 10⁻². This was done up to 10⁻⁴ dilution. Then 1 ml was taken from the 10⁻⁴ respectively into sterile Petri dishes and the molten agars that have been prepared earlier for bacterial growth were allowed to cool to about 45 °C before pouring into each of the sterile Petri-dishes and allowed to solidify. After solidification, each of the plates were incubated at 37 °C for the bacteria to grow between 24 h–48 h. After the incubation period each of the plates were examined and counted using Bacteria Colony Counter in terms of colony forming units.

2.6. Characterization and identification of bacterial isolates

The isolates were characterized and identified after obtaining pure culture of isolates through repeated sub-culturing by using their colonial morphology, cellular morphology and biochemical reaction and then identified by making reference to Bergey's manual of determinative bacteriology. Colonial and cellular morphology; Gram staining; motility test; biochemical tests (including catalase, coagulase, oxidation, indole, Urease, Voges-Proskauer, methyl red, starch hydrolysis and sugar

fermentation tests) were all conducted as described by Fawole and Oso [19].

2.7. Data analysis

The data were analyzed using IBM Statistical Package for Social Science (SPSS) version 20. All data are the mean of three replicates. The mean and standard deviation of each parameter were determined. The mean data were compared using one way Analysis of variance (ANOVA) and separated using Duncan Multiple Range Test (DMRT) at $\alpha = 0.05$. The percentage occurrence of bacteria was estimated based on positive and negative result from samples investigated. The following formula was used in estimating the percentage occurrence of bacteria in earthen and concrete tanks.

$$\text{Percentage occurrence (\%)} = \frac{\text{Number of positive results}}{\text{total number of samples examined}} \times 100$$

3. Results

3.1. Physicochemical parameters of earthen ponds and concrete tanks of selected farms

The present study was design to investigate the temporal patterns of water qualities, including the bacteriological and physicochemical profiles of static aquaculture systems, particularly those employing earthen ponds and concrete tanks.

The result from physicochemical analyses in earthen ponds showed significant variations between selected farms ($P < 0.05$), with DO ranges between 5.93 mg/l–6.43 mg/l, TDS range of 243 mg/l–451 mg/l, pH range of 6.47–7.47, electrical conductivity range of 0.34mS/cm–1.36mS/cm, temperature range of 28.07 °C–28.60 °C, alkalinity range of 43.43 mg/l–53.17 mg/l, total nitrogen range of 2.11 mg/l–2.93 mg/l and water hardness range of 15.81 mg/l–26.25 mg/l (Table 1a). Similarly, water quality measured between concrete water samples varies significantly ($P < 0.05$) in the DO range from 6.30 mg/l–6.77 mg/l; TDS range from 182.33 mg/l–306.67 mg/l; pH range from 6.80 to 8.27; electrical conductivity range from 0.25mS/cm–1.62mS/cm; temperature range from 28.10 °C–28.90 °C, alkalinity range of 48.40 mg/l–70.11 mg/l, total nitrogen range from 1.73 mg/l–2.18 mg/l and water hardness range of 20.44 mg/l–29.24 mg/l. (See Table 1b.)

3.2. Bacteriological counts of earthen ponds and concrete tanks in different sampling times

Bacteriological counts in earthen ponds, TVC, TCC and FCC, revealed a significant variation between sampling times the majority of the farms investigated ($P < 0.05$), with increasing load over time, except in the FCC derailing from this pattern (Table 2). The TVC, TCC and FCC of all the earthen pond water samples range from 5.10 ± 0.12 LogCFU/ml to 5.83 ± 0.04 LogCFU/ml, 4.46 ± 0.15 LogCFU/ml to 5.48 ± 0.03 LogCFU/ml and nil to 4.83 ± 0.13 LogCFU/ml respectively. Moreover, from the overall sampling time (Table 2), earthen pond water sampled

from Farm C had the highest TVC 5.64 ± 0.10 LogCFU/ml while that of Farm D had the least TVC 5.26 ± 0.21 LogCFU/ml. Similar is the case with TCC and FCC with TCC value of Farm C reaching 5.34 ± 0.10 LogCFU/ml while that of Farm D had the least TCC 4.83 ± 0.41 LogCFU/ml; and FCC value from Farm C recorded at 4.83 ± 0.13 LogCFU/ml and Farm D had least FCC 3.58 ± 0.81 LogCFU/ml. However, no FCC was recorded for Farm B. Furthermore, results recorded for bacteria counts in concrete ponds are presented in Table 3. This shows variation with time of sampling. In Table 3, the TVC, TCC and FCC of all the concrete tanks water samples ranged from 5.08 ± 0.07 LogCFU/ml to 5.67 ± 0.06 LogCFU/ml; 4.26 ± 0.24 LogCFU/ml to 5.36 ± 0.26 LogCFU/ml; and 0.00 to 4.77 ± 0.07 LogCFU/ml respectively. And grossly in concrete tanks, water sampled from Farm C had the highest TVC 5.39 ± 0.14 LogCFU/ml while that of Farm B had the least TVC 5.17 ± 0.25 LogCFU/ml. Where Farm E recorded the highest TCC 5.23 ± 0.11 LogCFU/ml while that of Farm B had the least TCC 4.81 ± 0.48 LogCFU/ml. Concrete water sampled from Farm E had the highest FCC 4.57 ± 0.11 Log CFU/ml while that of Farm A, Farm B and Farm C showed no value FCC counts.

Furthermore, the distribution of bacteria occurrence in farm waters at 3 different sampling occasions is presented in Table 4. Altogether, total 8 bacteria were isolated and their occurrence showed variation between farms, culturing facilities as well as temporal variation. Finally, in Table 5, the percentage occurrence of this bacteria group was estimated for the two enclosure systems (equation used for estimation is presented in the materials section of this article). In the case of earthen pond waters, *Staphylococcus spp* and *Enterobacter* group showed highest occurrence (20%) while *Proteus spp* and *Escherichia coli* showed lowest percentage occurrence of 8%. Similarly, in the concrete water sampled, *Staphylococcus spp* and *Enterobacter* group showed highest occurrence approximately 22% and 18% respectively. While lower occurrence was attributed to *Escherichia coli* and *Proteus spp* (8%), with lowest occurrence recorded for *Pseudomonas spp* (approx. 6%).

4. Discussion

The present study was designed to investigate the health status of aquaculture settings practicing stagnant water aquaculture. It is a well-established fact that water used for the culture of fish will not give maximum production if the 'physicochemical' parameters are not optimal for fish. And subsequently presenting fish to stressor(s) experience [36]. One outcome of this is increased susceptibility to diseases [8,20]. For example, channel catfish held in water with suboptimal quality (dissolved oxygen, carbon dioxide and ammonia) experienced reduced survival when injected intraperitoneally with sublethal doses of *Aeromonas hydrophila* conversely to fish kept in favorable water condition [46]. In the present study, all the parameters observed in earthen ponds and concrete tanks rearing enclosures were within the recommended range in the literature for aquaculture (e.g., [8,11]). A note of caution is due here, since it may first appear that feed supply is expected to elevate the nitrogenous wastes in the static aquaculture water, however, it may be appropriate to associate this low level of total nitrogen to

Table 1a
Physicochemical characteristics of earthen pond water from selected farms.

Farms	Earthen ponds Physicochemical parameters							
	DO (mg/l)	TDS (mg/l)	pH	EC (mS/cm)	T (°C)	ALK (mg/l)	TN (mg/l)	WH (mg/l)
A	6.17 ^b ± 0.06	243.33 ^a ± 0.58	6.83 ^b ± 0.06	0.34 ^b ± 0.00	28.60 ^b ± 0.00	53.17 ^e ± 0.15	2.12 ^a ± 0.01	19.53 ^b ± 0.03
B	5.93 ^a ± 0.06	322.67 ^a ± 0.58	7.47 ^c ± 0.06	0.45 ^c ± 0.00	28.43 ^a ± 0.06	44.07 ^b ± 0.06	2.43 ^b ± 0.01	26.25 ^c ± 0.01
C	6.43 ^c ± 0.11	451.00 ^c ± 5.29	6.47 ^a ± 0.15	0.62 ^d ± 0.01	28.07 ^a ± 0.06	43.43 ^a ± 0.32	2.11 ^a ± 0.01	16.42 ^a ± 0.01
D	6.10 ^b ± 0.10	265.33 ^b ± 1.16	7.33 ^c ± 0.06	1.36 ^e ± 0.04	28.27 ^a ± 0.55	45.17 ^c ± 0.06	2.93 ^d ± 0.01	16.47 ^a ± 0.01
E	6.23 ^b ± 0.06	281.61 ^c ± 1.16	6.63 ^a ± 0.15	0.14 ^a ± 0.02	29.87 ^b ± 0.70	46.37 ^d ± 0.15	2.73 ^c ± 0.01	15.81 ^a ± 0.96

Note: mean followed by the same superscript within the same column are not significantly different at $\alpha = 0.05$ based on Duncan Multiple Range Test (DMRT). DO (Dissolved oxygen); TDS (Total dissolved solids); EC (Electrical conductivity); T (Temperature); ALK (Alkalinity); NIT (Nitrate); WH (Water hardness).

Table 1b

Physicochemical parameters of concrete tanks water of selected farms.

Farms	Concrete tanks physicochemical parameters							
	DO (mg/l)	TDS (mg/l)	Ph	EC (mS/cm)	TEM (°C)	ALK (mg/l)	NIT (mg/l)	WH (mg/l)
A	6.43 ^a ± 0.06	218.33 ^a ± 3.79	7.70 ^b ± 0.10	0.25 ^a ± 0.01	28.60 ^c ± 0.00	59.37 ^c ± 0.06	1.73 ^a ± 0.29	22.17 ^c ± 0.12
B	6.30 ^a ± 0.00	306.67 ^c ± 0.58	6.80 ^a ± 0.00	0.43 ^d ± 0.00	28.10 ^a ± 0.10	48.83 ^b ± 0.23	1.73 ^a ± 0.06	29.24 ^d ± 0.09
C	6.67 ^b ± 0.06	231.33 ^d ± 0.58	7.70 ^b ± 0.10	0.32 ^c ± 0.00	28.37 ^b ± 0.06	48.40 ^a ± 0.20	1.77 ^a ± 0.15	20.44 ^a ± 0.01
D	6.67 ^b ± 0.15	219.67 ^b ± 1.53	8.10 ^c ± 0.10	1.62 ^e ± 0.00	28.90 ^d ± 0.00	68.43 ^d ± 0.02	2.15 ^b ± 0.06	22.13 ^c ± 0.01
E	6.77 ^b ± 0.06	221.33 ^c ± 15.7	8.27 ^c ± 0.23	0.29 ^b ± 0.02	28.17 ^a ± 0.12	70.11 ^e ± 0.01	2.18 ^b ± 0.06	21.18 ^b ± 0.01

Note: mean followed by the same superscript within the same column are not significantly different at $\alpha = 0.05$ based on Duncan Multiple Range Test (DMRT). DO (Dissolved oxygen); TDS (Total dissolved solids); EC (Electrical conductivity); T (Temperature); ALK (Alkalinity); NIT (Nitrate); WH (Water hardness).

Table 2

Bacteriological counts of Farm A-E earthen pond water of different sampling time.

	Sampling time	TVC (Log cfu/ml)	TCC (Log cfu/ml)	FCC (Log cfu/ml)
Farm A	1st sampling	5.41 ^a ± 0.08	5.04 ^a ± 0.07	4.54 ^b ± 0.28
	2nd sampling	5.61 ^a ± 0.15	5.28 ^b ± 0.05	2.77 ^{ab} ± 2.40
	3rd sampling	5.83 ^b ± 0.04	5.48 ^c ± 0.03	0.00 ^a ± 0.00
Farm B	1st sampling	5.11 ^a ± 0.10	4.83 ^a ± 0.16	0.00 ± 0.00
	2nd sampling	5.46 ^b ± 0.13	5.03 ^{ab} ± 0.12	0.00 ± 0.00
	3rd sampling	5.52 ^b ± 0.13	5.14 ^b ± 0.10	0.00 ± 0.00
Farm C	1st sampling	5.56 ^a ± 0.14	5.25 ^a ± 0.11	0.00 ^a ± 0.00
	2nd sampling	5.61 ^a ± 0.09	5.33 ^a ± 0.14	4.83 ^b ± 0.13
	3rd sampling	5.76 ^a ± 0.09	5.44 ^a ± 0.12	0.00 ^a ± 0.00
Farm D	1st sampling	5.10 ^a ± 0.12	4.46 ^a ± 0.15	4.39 ^b ± 0.36
	2nd sampling	5.17 ^a ± 0.09	4.75 ^a ± 0.18	0.00 ^a ± 0.00
	3rd sampling	5.50 ^a ± 0.09	5.27 ^b ± 0.14	2.77 ^{ab} ± 2.40
Farm E	1st sampling	5.26 ^a ± 0.15	4.59 ^a ± 0.11	0.00 ^a ± 0.00
	2nd sampling	5.41 ^a ± 0.07	4.97 ^b ± 0.14	4.26 ^b ± 0.24
	3rd sampling	5.62 ^b ± 0.07	5.38 ^c ± 0.06	0.00 ^a ± 0.00

Means with the same superscript in columns are not significantly different at $\alpha = 0.05$ based on the Duncan Multiple Range Test (DMRT). TVC (Total Viable Count); TCC (Total Coliform Count); FCC (Fecal Coliform Count) Note: Values presented as mean ± standard deviation of triplicates.

Table 3

Bacteriological counts of Farm A-E concrete tank water of different sampling time.

	Sampling time	TVC (Log cfu/ml)	TCC (Log cfu/ml)	FCC (Log cfu/ml)
Farm A	1st sampling	5.16 ^a ± 0.15	4.88 ^a ± 0.16	0.00 ± 0.00
	2nd sampling	5.11 ^a ± 0.07	4.97 ^a ± 0.20	0.00 ± 0.00
	3rd sampling	5.67 ^b ± 0.06	5.36 ^b ± 0.26	0.00 ± 0.00
Farm B	1st sampling	5.46 ^a ± 0.09	5.19 ^a ± 0.10	0.00 ± 0.00
	2nd sampling	4.99 ^a ± 0.14	4.26 ^a ± 0.24	0.00 ± 0.00
	3rd sampling	5.09 ^b ± 0.13	4.99 ^b ± 0.14	0.00 ± 0.00
Farm C	1st sampling	5.23 ^a ± 0.08	4.92 ^a ± 0.21	0.00 ± 0.00
	2nd sampling	5.44 ^b ± 0.06	5.20 ^{ab} ± 0.10	0.00 ± 0.00
	3rd sampling	5.50 ^b ± 0.04	5.29 ^b ± 0.11	0.00 ± 0.00
Farm D	1st sampling	5.17 ^{ab} ± 0.06	5.03 ^b ± 0.12	4.77 ^b ± 0.07
	2nd sampling	5.08 ^a ± 0.07	4.63 ^a ± 0.31	4.00 ^a ± 0.00
	3rd sampling	5.25 ^b ± 0.07	5.08 ^b ± 0.07	4.26 ^a ± 0.24
Farm E	1st sampling	5.22 ^a ± 0.10	5.11 ^a ± 0.10	0.00 ^a ± 0.00
	2nd sampling	5.29 ^a ± 0.10	5.27 ^{ab} ± 0.11	4.46 ^b ± 0.15
	3rd sampling	5.53 ^b ± 0.06	5.32 ^b ± 0.07	4.67 ^b ± 0.19

Means with the same superscript in columns are not significantly different at $\alpha = 0.05$ based on the Duncan Multiple Range Test (DMRT). TVC (Total Viable Count); TCC (Total Coliform Count); FCC (Fecal Coliform Count) Note: Values presented as mean ± standard deviation of triplicates.

the increased utilization by present bacteria [38]. This is a similar principle in conventional static water aquaculture systems, biofloc system [33] and aqua-mimicry [34,35]. In which the nitrogenous wastes including ammonia is converted to bacterial biomass [38]. This is especially beneficial for aquaculture performance. For example, it has

been documented that freshwater fish reared at 0, 10, and 100 mg/l nitrate showed increased specific growth rate and food conversion efficiency relative to higher nitrate concentration (e.g., >100–1000 mg/l) [28]. Another possible explanation for the low nitrogen level is the fact that water residence time may allow for proper utilization of nitrogenous waste, since retention time often influences the activity of heterotrophic denitrifiers. For this reason, the use of static water aquaculture system may render no adverse effect on aquaculture performances. However, the biological features, including microbial trend in this stagnant environment should be investigated.

In the present study, we investigated the bacterial profile of static aquaculture systems (in earthen ponds and concrete tanks). The most obvious finding to emerge from bacteria analyses of different sampling time is the increased concentration of total viable and coliform bacteria counts (TVC and TCC, Tables 2 & 3). Contrary to expectation, unlike earthen pond waters, this trend was not experienced in concrete tank waters (Table 3). A possible explanation for this might be the fact that the majority of farm operators using concrete water aquaculture replenish the water use due to inability of the concrete rearing environment to naturally process wastes relative to earth ponds [25,26]. Which otherwise could result in reduced performance of the stock [12]. Therefore, one associable consequence of increasing concentration over time is the possible increase in pathogenic challenges over time, probably due to accumulation of organic substrates. Because it has been reported that growth of pathogenic bacteria such as *Escherichia coli*, *Vibrio cholerae* and *Pseudomonas aeruginosa* is affected by the composition and concentration of organic carbon in the water [44]. Collectively, the presence of Gram-negative bacteria provides indication of presence of pathogenic bacteria groups. Especially, the presence of *Escherichia coli* provides indication of presence of pathogens [5]. Although not isolated from this study, *Vibrio cholerae*, a pathogenic bacteria, has been isolated in other regions from aquaculture rearing facilities [30] and has been implicated to account for several diarrhea cases in Nigeria. For example, in the 2017 incident in the Ilorin metropolis, the culture positive rate of the *Vibrio cholerae* isolates was 41% [4]. Compared to the 78% level of occurrence reported by Borah et al. [7], *Escherichia coli* found in the present study was lower (8%) in both rearing enclosures and the regular trend recorded for other bacteria groups (TVC and TCC) was not witnessed for the fecal coliform group (Tables 2 & 3). It seems appropriate to associate this irregularity recorded to the long-time exposure to solar radiation [9] due to minimal water exchange. Because long term exposure to UV radiation has been claimed to inactivate *E. coli* cells [29]. In fact, up to 90% of *E. coli* cells have been reported to be disrupted by sunlight exposure [9].

Before proceeding to examining the favorability of isolated bacteria, it is important to mention that during the period of study, no gross signs of disorders were observed in all farms, except in farm A with cases of mass mortalities. This low infection incidence may be reasonable associated with high tolerance of the culture species, *Clarias gariepinus* in the culture area [32]. Nevertheless, other isolated bacteria including *Bacillus spp* and *Staphylococcus spp* form beneficial components of the pond ecosystem. Due to constant contact and inevitable ingestion of

Table 4

Distribution of occurrence of Bacterial species of earthen pond water.

Bacterial isolates	Farm A earthen pond water 1st 2nd 3rd			Farm B earthen pond water 1st 2nd 3rd			Farm C earthen pond water 1st 2nd 3rd			Farm D earthen pond water 1st 2nd 3rd			Farm E earthen pond water 1st 2nd 3rd		
<i>Staphylococcus spp</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Streptococcus spp</i>	+	–	–	–	–	+	+	–	–	+	+	–	+	+	+
<i>Proteus spp</i>	–	+	+	+	+	+	+	–	–	–	–	+	–	–	–
<i>Enterobacter spp</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Serratia spp</i>	+	–	+	+	+	+	+	–	–	+	+	+	+	+	–
<i>Bacillus spp</i>	+	–	–	–	–	–	+	–	–	–	+	+	+	+	+
<i>Escherichia coli</i>	+	+	–	–	–	–	–	+	–	–	+	–	–	+	–
<i>Pseudomonas spp</i>	–	–	–	–	+	–	–	+	–	–	–	+	+	+	–

Bacterial isolates	Farm A concrete tank water 1st 2nd 3rd			Farm B concrete tank water 1st 2nd 3rd			Farm C concrete tank water 1st 2nd 3rd			Farm D concrete tank water 1st 2nd 3rd			Farm E concrete tank water 1st 2nd 3rd		
<i>Staphylococcus spp</i>	+	+	+	+	–	–	+	+	+	+	+	–	+	+	+
<i>Streptococcus spp</i>	–	+	+	–	+	+	+	+	+	+	+	–	–	–	–
<i>Proteus spp</i>	–	+	–	–	+	+	–	–	+	–	–	–	–	–	+
<i>Enterobacter spp</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Serratia spp</i>	+	–	+	+	–	–	+	–	–	–	+	–	–	–	–
<i>Bacillus spp</i>	+	+	–	–	+	+	+	+	+	+	+	–	–	–	+
<i>Escherichia coli</i>	–	–	–	–	–	–	–	–	–	+	+	+	–	+	+
<i>Pseudomonas spp</i>	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–

Key: (+) presence of bacteria isolate, (–) absence of bacteria isolates.

Table 5

Percentage occurrence of bacteria in earthen pond water.

Bacteria	Percentage occurrence (%)	
	Earthen ponds	Concrete tanks
<i>Staphylococcus spp</i>	20	17.91
<i>Streptococcus spp</i>	12	16.41
<i>Proteus spp</i>	8	7.46
<i>Enterobacter spp</i>	20	22.39
<i>Serratia spp</i>	16	7.46
<i>Bacillus spp</i>	9.33	14.93
<i>Escherichia coli</i>	8	7.46
<i>Pseudomonas spp</i>	6.67	5.97

surrounding water, farmed fish are strongly influenced by the micro-organisms contained in the water [13,16]. For example, previous research has established that there is similarity between intestinal and culture water microbiota [47]. In the study area investigated, of the bacteria group isolated, *Staphylococcus spp* appeared to show the highest occurrence (up to 18–20%). This gives an indication that cultured stock may benefits, on one hand, from the antimicrobial effects of these bacteria [37,42] and, on the other hand, may enhance food utilization relevant for aquaculture performances. For instance, using *Bacillus sp* and photosynthetic bacteria isolated from carp ponds as probiotics, Yanbo & Zirong [48] reported a significant increase in growth performance and FCR. However, a note of caution is due here, due to the static water aquaculture practice in the study area, there is risk of opportunistic infection, as a result of overwhelming growth of bacteria or prolonged stimulation time of immune response [10].

5. Conclusion

Undoubtedly, the open nature of aquaculture environments limits the total exclusion of pathogens. In light of recent event on aquatic environmental quality deterioration, it is becoming extremely difficult to ignore the significance of investigating the water quality profile in aquaculture environment. In the present study, we investigated the physicochemical and bacteria profiles of aquaculture systems practicing static water exchange. Although all physicochemical parameter were within the recommended range for freshwater aquaculture, however, bacteriological observation reported in this study demonstrated potential health threats to fish stocks or the adjacent aquatic environment

upon end-of-production effluent discharge. The bacteriological counts indicated a potential increment in pathogenic challenge in the static aquaculture environment, as indicated in the temporal growth pattern recorded for several bacteria groups. In the study, area, the appearance of *Escherichia coli* indicated the possible presence of pathogenic bacteria of enteric origin. Arguably, compared to other livestock zoonosis, there has not been enough evidence examining the relationships between aquaculture originated pathogens and workers health, however, it may be inferred from the present study that static aquaculture system may serve as ultimate source of pathogenic bacteria to the public through end of production water discharge. Nevertheless, this is an area requiring attention especially with mounting concern over ‘one health initiatives’.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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