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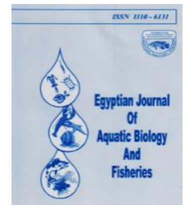

Impact of African Catfish (*Clarias gariepinus*) Bioturbation on Water and Soil Quality

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ABSTRACT

Bioturbation refers to the disturbance and mixing of sediments and the overlying water column, resulting from the burrowing, feeding, and movement activities of benthic organisms. This study aimed to evaluate the impact of bioturbation by African catfish (*Clarias gariepinus*) on selected water and soil quality parameters under controlled conditions over an 11-day period. Three treatments were established. Treatments II and III involved soil amended with approximately 500mg/ kg of ammonium nitrogen, while Treatment I included no soil. In addition, *C. gariepinus* was introduced as a bioturbator in Treatment III. The results indicated no significant differences in temperature, dissolved oxygen, or total dissolved solids between morning and afternoon measurements across all treatments. However, pH levels showed significant differences in the morning between Treatment I and treatments II and III, though these differences were not observed in the afternoon. Total ammonia-nitrogen levels also differed significantly in the morning between Treatment I and the other treatments, with no significant variation in the afternoon. Nitrite concentrations were significantly higher in Treatment III compared to treatments I and II, both in the morning and afternoon. Phosphorus levels showed no significant differences in the morning but were significantly elevated in the afternoon in Treatment III relative to the other treatments. In terms of soil quality, ammonia-nitrogen levels in treatments II and III declined over time, from 500.00 ± 0.00 to 83.33 ± 0.00 mg/L. Soil pH values decreased slightly, ranging from 9.00 ± 0.00 to 8.33, while phosphorus concentrations remained stable at 120.00 ± 0.00 mg/L throughout the study. These findings suggest that *C. gariepinus* acts as an effective bioturbator, enhancing sediment–water interactions. However, its influence on key water quality parameters underscores the importance of continuous monitoring and implementation of appropriate management practices in aquaculture or integrated systems.

INTRODUCTION

Soil and water quality are fundamental to the sustainability and productivity of pond aquaculture. While water quality management has traditionally received more attention,

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the role of pond bottom soil has often been overlooked. However, recent studies have highlighted the significant influence of soil conditions and soil–water interactions in maintaining overall water quality **(Boyd, 2002)**.

The African catfish (*Clarias gariepinus*) is a widely introduced species in the Philippines and is found across many freshwater ecosystems worldwide **(Chirwa *et al.*, 2019)**. Its introduction has been associated with considerable ecological disruptions, particularly affecting adjacent trophic levels.

With the intensification of aquaculture practices—especially increased stocking densities and feeding rates—only a small fraction of the nitrogen, phosphorus, and organic carbon in feed is assimilated into fish biomass. The remainder accumulates in the pond environment **(Anschutz *et al.*, 2012)**. Organic matter from uneaten feed and metabolic waste settles at the pond bottom, enriching the sediments with nutrients. As oxygen is gradually depleted with depth, anaerobic conditions often develop in the bottom soil **(Nicholaus & Zheng, 2014)**.

The resuspension and mixing of bottom sediments expose organic matter to oxygenated water, potentially activating aerobic decomposition processes. Such disturbance can occur through mechanical means—such as aerators or dragging chains across the pond floor—or naturally via the activities of benthic organisms, a process known as bioturbation **(Meijer & Avnimelech, 1999; Phan-Van *et al.*, 2008; Martinez-Garcia *et al.*, 2015)**.

Bioturbation refers to the reworking and mixing of sediments through the burrowing, feeding, and movement of benthic organisms and benthivorous fish **(De Haas *et al.*, 2005; Meysman *et al.*, 2006; Zhao *et al.*, 2018)**. These biological activities—including irrigation, resuspension, secretion, excretion, and locomotion—alter the physical structure of sediments, thereby influencing the diffusion and/or advection of solutes and particulates **(Adámek & Maršálek, 2012)**. This process facilitates nutrient mineralization and promotes the release of nutrients into the overlying water column **(Chakraborty *et al.*, 2022)**.

Benthivorous fish further influence aquatic ecosystems by altering water clarity, nutrient cycling, and the composition of phytoplankton, macrophyte, zooplankton, and benthic communities. Among these species, the African catfish is notable not only for its economic importance but also for its potential ecological role in promoting bioturbation **(Northcote, 1988)**.

Despite the increasing recognition of bioturbation in aquaculture systems, most existing studies have focused on carp and other species. Limited research has been conducted on the bioturbation potential of *C. gariepinus* and its role in sediment–water exchanges. Therefore, the present study aimed to evaluate and characterize the effects of the African catfish bioturbation on selected soil and water quality parameters under controlled aquarium conditions.

MATERIALS AND METHODS

1. Soil collection and analysis

Soil samples were collected from fishponds at the Freshwater Aquaculture Center (FAC), Central Luzon State University (CLSU). The collected soil was sterilized and amended with ammonium chloride at a rate of 10g/ kg to increase ammonia concentration. To achieve this, ammonium chloride was first dissolved in 10mL of distilled water and was then sprayed evenly onto the soil to attain a target concentration of 500mg of ammonium nitrogen per kilogram of soil. After treatment, the soil was analyzed for ammonium nitrogen, pH, and phosphorus levels at the Soil and Water Quality Laboratory of FAC–CLSU using a standard soil test kit.

2. Experimental design and setup

A Completely Randomized Design (CRD) was employed, consisting of three treatments with three replications each (Table 1). The experimental units consisted of aquaria with a 60-liter capacity.

- Treatment I served as the negative control and contained no soil.
- Treatments II and III were prepared with a 2 cm-thick layer of pond soil containing approximately 500mg/ kg of ammonium nitrogen.
- Each aquarium in Treatment III was stocked with two African catfish (*Clarias gariepinus*), with an average body weight of 134.00 ± 10.89 g.

Tap water was gently added to each aquarium until a water depth of 30cm was achieved. Fish in Treatment III were fed commercial feed on an ad libitum basis, twice daily. The experiment was conducted over a period of 11 days.

Table 1. Description of treatment groups used in the study

Treatment	Description
I	Negative control
II	Positive control
III	With bioturbation

3. Data collection

Water and soil quality parameters were monitored twice daily, at 10:00 AM and 3:00 PM, throughout the experimental period. Water quality parameters—including temperature, dissolved oxygen (DO), pH, and total dissolved solids (TDS)—were measured using a YSI multi-parameter probe. Additionally, total ammonia-nitrogen (TAN), nitrite, and phosphorus concentrations in the water were analyzed using colorimetric methods with a spectrophotometer, following standard laboratory procedures.

For soil analysis, parameters such as ammonium nitrogen, pH, and phosphorus were assessed using a standard soil test kit.

4. Statistical analysis

Using the STAR, version 2.0.1 2014 software, data were expressed as the mean ± standard deviation. For the water quality analysis, variations were assessed by the analysis of variance. Post-hoc Tukey's multiple range tests were performed to compare the differences between the means at 5% probability ($P< 0.05$). The daily averages of water and soil quality parameters were illustrated using graphical representations.

RESULTS

1. Water quality analysis

The results of the physico-chemical analysis of water quality parameters are presented in Table (2). Water temperature remained constant across all treatments (I, II, and III) regardless of time intervals, indicating that the presence or absence of bioturbation had no significant effect on thermal conditions.

Dissolved oxygen (DO) concentrations were significantly higher in Treatment I compared to treatments II and III. A similar decreasing trend was observed in pH values, with Treatment I exhibiting significantly higher pH than treatments II and III.

In contrast, total dissolved solids (TDS) increased significantly across treatments, with the highest values recorded in Treatment III, as illustrated in Fig. (1). Regarding nutrient concentrations, particularly total ammonia-nitrogen (TAN), Treatment I showed significantly lower values compared to treatments II and III during the morning, although no significant differences were found among treatments during the afternoon.

Nitrite concentrations in Treatment I were also significantly different from those in Treatments II and III during both morning and afternoon measurements. Phosphorus concentrations did not differ significantly among treatments in the morning. However, in the afternoon, Treatment III exhibited significantly higher phosphorus levels compared to treatments I and II.

Table 2. The results of water quality analysis with and without the use of African catfish (*Clarias gariepinus*) bioturbator during the experiment

Water Quality Parameter	Treatments and Sampling Hours					
	Treatment I		Treatment II		Treatment III	
	10:00 AM	03:00 PM	10:00 AM	03:00 PM	10:00 AM	03:00 PM
Temperature	27.82 ± 0.84[a]	28.33 ± 0.74[a]	27.85 ± 0.81[a]	28.49 ± 0.68[a]	27.85 ± 0.81[a]	28.56 ± 0.64[a]
Dissolved oxygen (mg/L)	5.69 ± 0.50[a]	5.64 ± 0.62[a]	3.66 ± 0.60[b]	2.79 ± 1.40[b]	1.08 ± 0.97[c]	0.99 ± 0.93[c]
pH	7.16 ± 0.13[a]	7.30 ± 0.13[a]	7.04 ± 0.10[b]	7.12 ± 0.05 [b]	7.03 ± 0.10[b]	6.98 ± 0.35[c]

Total dissolved solids (mg/L)	189.06 ± 3.47[c]	191.03 ± 4.31 [c]	996.67 ± 194.72 [b]	1079.61 ± 227.31[b]	1883.36 ± 95.14[a]	1920.45 ± 112.56[a]
Total ammonia-nitrogen (mg/L)	0.0868 ± 0.03[b]	0.0682 ± 0.02[c]	0.5468 ± 0.24[a]	0.4788 ± 0.20[b]	0.5729 ± 0.32[a]	0.6350 ± 0.34[a]
Nitrite (mg/L)	0.0188 ± 0.00[b]	0.0249 ± 0.2[b]	0.0201 ± 0.00[b]	0.0217 ± 0.01[b]	0.0641 ± 0.05[a]	0.0867 ± 0.08[a]
Phosphorus (mg/L)	0.1011 ± 0.01[c]	0.1004 ± 0.00[b]	0.1319 ± 0.01[b]	0.1396 ± 0.01[b]	0.4394 ± 0.11[a]	0.4916 ± 0.14[a]

*Mean in rows with different letter superscripts are significantly different at $P< 0.05$.

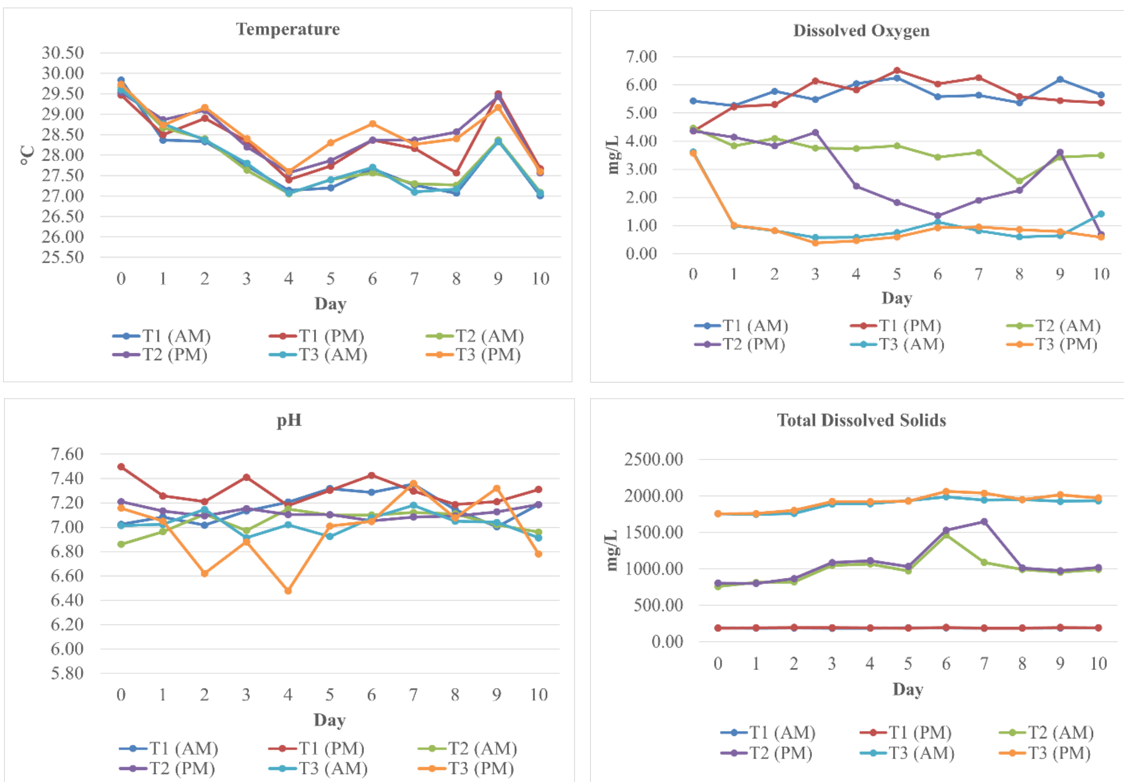

Fig. 1. Daily variations of water quality parameters tested during the experiment

2. Soil quality analysis

The results of soil quality parameters—ammonium nitrogen, pH, and phosphorus—are presented in Tables (3, 4). Ammonium nitrogen concentrations showed a general declining trend in both treatments II and III over the 11-day period. In Treatment II, levels fluctuated during the initial days, with secondary peaks observed on Day 2 and Day 6, followed by a steady decline from Day 7 onward, reaching 83.33 mg/L (AM) and 66.67 mg/L (PM) by Day 10. In contrast, Treatment III exhibited a more consistent and rapid decrease, with concentrations dropping from 500.00mg/ L on Day 0 to 66.67mg/ L (AM) and 50.00mg/ L (PM) by the end of the experimental period.

pH values in both treatments remained relatively stable, ranging from 8.0 to 9.0 throughout the study. Treatment II showed more consistent pH levels, whereas Treatment III exhibited slightly greater variability, particularly during the initial days.

Phosphorus concentrations remained unchanged at 120.00mg/ L in both treatments II and III across the entire observation period, indicating no measurable variation in phosphorus content. These trends are illustrated in Fig. (2).

Table 3. The results of soil quality analysis (10:00 AM) with and without African catfish (*Clarias gariepinus*) bioturbation during the experiment

Parameter	Treatment	Days										
		0	1	2	3	4	5	6	7	8	9	10
Ammonium nitrogen (mg/L)	II	500.00 ±0.00	200.00 ±0.00	500.00 ±0.00	366.67 ±188.56	133.33 ±47.14	266.67 ±169.97	400.00 ±141.42	200.00 ±0.00	100.00 ±0.00	100.00 ±0.00	83.33 ±0.00
	III	500.00 ±0.00	350.00 ±259.81	400.00 ±173.21	366.67 ±230.94	300.00 ±173.21	266.67 ±208.17	500.00 ±0.00	83.33 ±28.87	100.00 ±0.00	83.33 ±28.27	66.67 ±28.87
pH	II	9.00 ±0.00	8.00 ±0.00	8.67 ±0.47	8.33 ±0.47	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00
	III	9.00 ±0.00	8.00 ±0.00	8.67 ±0.58	8.00 ±0.00	8.33 ±0.58	8.67 ±0.58	8.33 ±0.58	8.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00
Phosphorus (mg/L)	II	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ± 0.00	120.00 ±0.00	120.00 ± 0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00
	III	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ± 0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00

All values are expressed as mean ± standard deviation.

Table 4. Results of soil quality analysis (3:00 PM) with and without African catfish (*Clarias gariepinus*) bioturbation during the experiment

Parameters	Treatment	Days										
		0	1	2	3	4	5	6	7	8	9	10
Ammonium nitrogen (mg/L)	II	500.00 ±0.00	200.00 ±0.00	500.00 ±0.00	366.67 ±188.56	200.00 ±173.21	400.00 ±141.42	400.00 ±141.42	133.33 ±0.00	83.33 ±23.57	100.00 ±0.00	66.67 ±23.57
	III	500.00 ±0.00	366.67 ±230.94	100.00 ±0.00	233.33 ±230.94	266.67 ±208.17	300.00 ±173.21	266.67 ±208.17	83.33 ±28.87	83.33 ±23.87	83.33 ±23.87	50.00 ±0.00
pH	II	9.00 ±0.00	9.00 ±0.00	8.00 ±0.00	9.00 ±0.00	9.00 ±0.00	9.00 ±0.00	8.67 ±0.47	9.00 ±0.00	8.67 ±0.47	8.67 ±0.47	9.00 ±0.00
	III	9.00 ±0.00	9.00 ±0.00	8.00 ±0.00	9.00 ±0.00	8.00 ±0.00	9.00 ±0.00	8.33 ±0.58	9.00 ±0.00	9.00 ±0.00	8.33 ±0.58	9.00 ±0.00
Phosphorus (mg/L)	II	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00
	III	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00	120.00 ±0.00

All values are expressed as mean ± standard deviation.

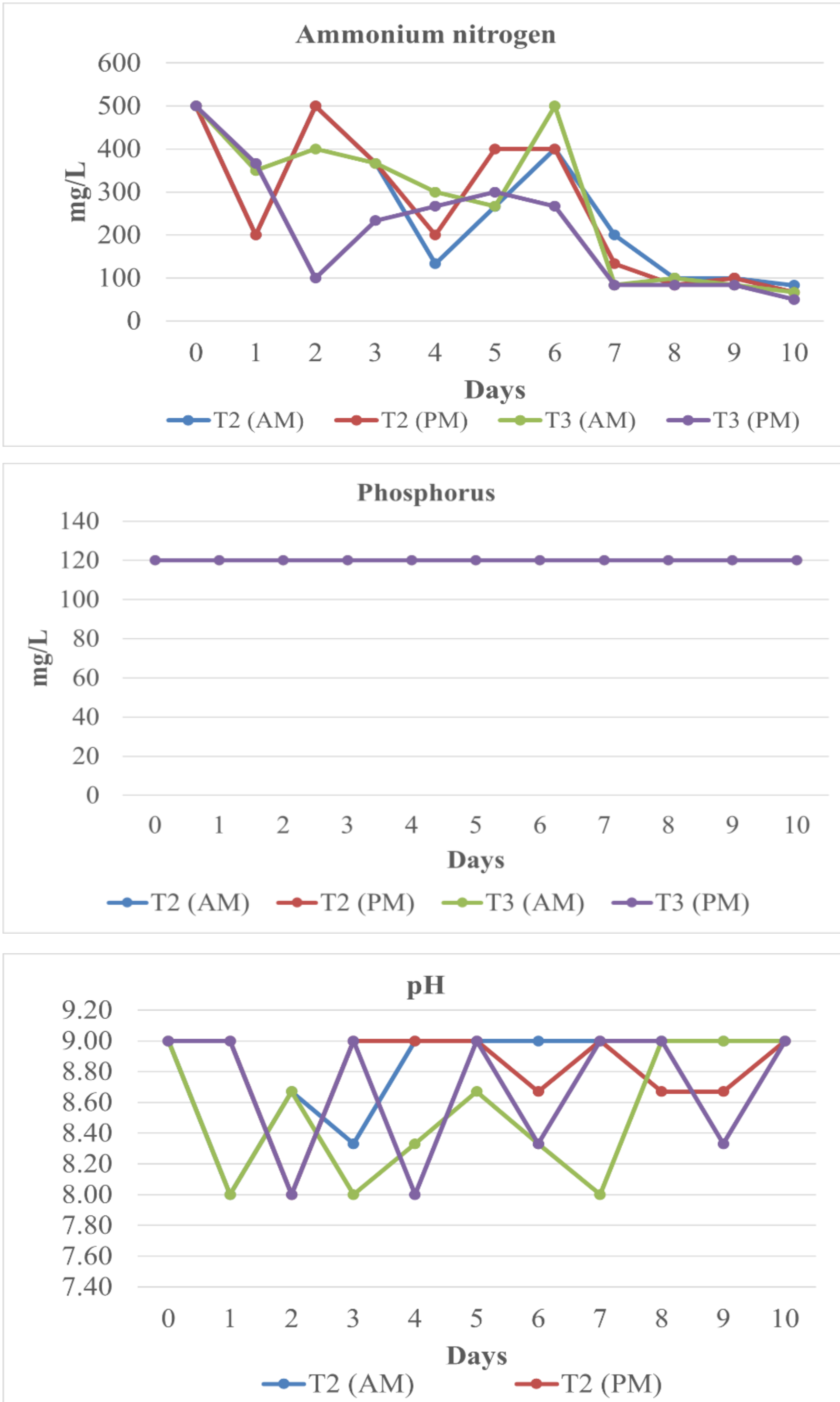

Fig. 2. Profile of soil quality throughout the experimental period

DISCUSSION

Nitrification is a microbial process in which ammonia is oxidized to nitrate. This nitrate may then undergo denitrification to form gaseous nitrogen or be converted back into

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ammonium through nitrate ammonification. These processes are strongly influenced by water quality parameters such as dissolved oxygen, temperature, and pH **(Zhong *et al.*, 2014)**.

In the present study, the use of African catfish (*Clarias gariepinus*) as a bioturbator inhibited, rather than promoted, the nitrification process over the 11-day experimental period. This outcome deviated from the initial expectation that bioturbation would reduce inorganic compounds—particularly total ammonia-nitrogen (TAN). Since soil ammonia was deliberately elevated to evaluate nutrient exchange between sediments and overlying water, the observed outcomes suggest that fish bioturbation enhanced denitrification and nitrate ammonification. Similar results were reported by **Zhong *et al.* (2014)**, who found that bioturbation by benthic organisms did not support nitrification, thereby maintaining elevated TAN concentrations.

Moreover, the indoor setup—characterized by limited natural light and reduced air circulation—may have further suppressed oxygen availability. The excretion of *C. gariepinus* also contributed additional ammonia to the system, potentially exacerbating TAN levels. This aligns with findings by **Reyes and Estrada (2019)**, who reported that catfish bioturbation did not significantly reduce TAN concentrations. Similarly, **Adámek and Maršálek (2012)** concluded that fish presence alone does not reduce ammonia-nitrogen levels in aquaculture systems.

Nitrite, the intermediate product in nitrification, is highly toxic to aquatic organisms if not maintained within safe limits **(Ciji & Akhtar, 2019)**. Elevated nitrite concentrations are typically associated with stimulated nitrification, which can occur when nitrite-oxidizing bacteria are impaired due to low dissolved oxygen, high organic load, or environmental stressors such as temperature and pH fluctuations **(Ritvo *et al.*, 2004)**. Although bioturbation by some macrobenthic organisms can improve oxygen penetration and stimulate nitrifiers along burrow walls **(Gabet *et al.*, 2003)**, such effects were not evident in this study. Instead, consistently high nitrite concentrations in Treatment III suggest disrupted nitrogen cycling, likely due to low oxygen levels and limited light, which inhibited complete ammonia oxidation.

Significant changes in pH, TDS, TAN, and nitrite observed in this study contrast with those of **Reyes and Estrada (2019)**, who found no notable effects of fish bioturbation on these parameters under different experimental conditions. However, the present results support the notion that bioturbation increases turbidity through sediment resuspension and enhances the movement of dissolved and particulate matter across the sediment–water interface **(Ritvo *et al.*, 2004; Croel & Kneitel, 2011)**. This mechanism likely contributed to the significantly higher TDS concentrations observed in the bioturbated treatments.

Phosphorus is a key limiting nutrient in aquatic ecosystems **(Chakrabarty & Das, 2006)**, but in excess, it becomes a major pollutant leading to eutrophication. In the current study, phosphorus concentrations fluctuated early on but stabilized at low levels toward the end of the experiment. This trend supports findings by **Zhao *et al.* (2018)**, who noted that bioturbation by clams facilitated the release of organic phosphorus into the water. Uneaten feed could also have contributed to phosphorus accumulation. Nonetheless, **Martinez-Garcia *et al.* (2015)** reported that bioturbation by *Hediste diversicolor* had no effect on phosphorus fluxes, highlighting species-specific outcomes.

Pond bottom soil and sediment accumulation play critical roles in aquaculture ecosystems. Bioturbation enhances nutrient fluxes, particularly of nitrogen and phosphorus, across the sediment–water interface. Sediment oxygen levels are typically lower due to high rates of organic matter decomposition **(Adámek & Maršálek, 2012)**. Thus, bioturbator activity can improve oxygen penetration, accelerating mineralization and releasing nutrients into the water column **(Fukuhara & Sakamoto, 1987; Jana & Das, 1992; Jana & Sahu, 1993; Hansen *et al.*, 1998; Brönmark & Hansson, 2005)**.

This mechanism is reflected in the present study, where soil ammonium nitrogen decreased over time in the bioturbated treatment, while dissolved oxygen declined and TAN, nitrite, and phosphorus increased in the water column. In contrast, soil phosphorus remained stable throughout the experiment, showing no translocation despite enhanced bioturbation activity.

Soil pH levels in treatments II and III consistently exceeded 8.5, with slightly higher values in the bioturbated group. This may be due to increased aeration and organic matter decomposition, which release basic ions and carbon dioxide into the sediment **(Mermillod-Blondin & Rosenberg, 2006)**. As discussed, the burrowing and feeding behavior of benthic organisms like the African catfish can restructure sediments and promote oxygen diffusion, which may contribute to improved bottom soil quality in aquaculture ponds **(Ritvo *et al.*, 2004; De Haas *et al.*, 2005; Meysman *et al.*, 2006)**.

CONCLUSION

Bioturbation by *Clarias gariepinus* had a direct impact on both water and soil quality. In the water column, bioturbation led to a decrease in dissolved oxygen and pH, while causing increases in total dissolved solids, total ammonia-nitrogen, nitrite, and phosphorus, primarily due to sediment disturbance and nutrient release. In the soil, bioturbation accelerated the reduction of ammonium nitrogen, indicating enhanced nutrient cycling processes. However, soil pH and phosphorus concentrations remained relatively stable throughout the study. These findings suggest that *C. gariepinus* functions as an effective bioturbator, enhancing sediment–water interactions. Nonetheless, its influence on water quality parameters highlights the need for careful monitoring and management in aquaculture systems to avoid potential negative impacts.

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