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TEMPORAL DYNAMICS OF PHYSICOCHEMICAL WATER QUALITY PARAMETERS IN AQUACULTURE POND

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ABSTRACT

In aquaculture production, water is held inside a fish pond for a certain period before discharging or recycling. During this period, the characteristics of the water vary due to the addition of fish feed and chemicals, as well as the fish metabolites. This study evaluated the temporal dynamics of the physicochemical water quality parameters in fish ponds. Grab samples were collected daily over 30 days, and physicochemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), major cations and metals were evaluated. The concentrations of the cations fluctuated over the period, with the Ca having the highest variations. The highest concentration (19 mg/L) was observed on the 5th day whilst the lowest (12 mg/L) was observed on the 23rd day. The concentration of Mg fluctuated over the period, with an average of 4.35 mg/L. Overall, the concentrations of these cations in the pond water are in the following order: Ca > Mg > K, which indicates that the water is unlikely to pose any harmful effect on soil hydraulic conductivity. The concentrations of the metallic ions in the pond also varied over the period. However, the exit concentrations are below the recommended threshold values for irrigation. The SAR analysis showed an increasing trend over the period, with the value exceeding the FAO recommended threshold from the 14th day. This study has shown that most of the physicochemical parameters of the pond water fluctuate over time, but the effluent can still be used for irrigation.

Keywords: Aquaculture effluents, Sustainability, Irrigation water quality, Wastewater

INTRODUCTION

The aquaculture industry has rapidly expanded in the last few decades, with global annual production reaching 126 million tonnes in 2020 (Mair et al., 2023). The significance of the aquaculture industry is expected to increase as the global population continues to increase with the concomitant demand for food and nutrition. In Sub-Saharan Africa, Nigeria is the largest aquaculture producer, producing about 291,323 tonnes in 2018 (World Bank, 2021). The industry is therefore considered important for Nigerian economic development as it provides direct employment to many people. However, despite its economic benefits, intensive aquaculture poses a significant environmental problem due to the production of large quantities of effluents, comprising wastewater and sediments, that must be properly managed to prevent environmental pollution.

Aquaculture effluents is a complex mixture of wastewater and sediments, which contain large quantities of organic pollutants (including nitrogen and phosphorous), from the fish feeds. It is estimated that for every 1 kg of live-weight fish, about 1 – 3 kg of feed will be required and 36% of this feed will be excreted as wastes (Endut et al., 2011; Naylor et al., 2000). In addition, about 75% of the nitrogen and phosphorous present in the feeds are not utilized and end up in the wastewater (Gutierrez-wing and Malone, 2006). The presence of large quantities of nutrients in aquaculture may result in environmental pollution, including eutrophication in the receiving water bodies (Coldebella et al., 2018). The impacts of aquaculture effluents on the environment have been well documented. For example, Mgbemena et al., (2021) evaluated the potential impact of aquaculture effluents from fish farms in Anambra, Imo and Lagos States of Nigeria and concluded that the organic loads could lead to environmental pollution. In their study on the impact of aquaculture effluents in Kenya, Wairimu et al., (2019) reported that effluents are causing environmental deterioration and highlighted the need for effective treatment prior to discharge. (Akinsulire et al., 2018) have also reported the impact of aquaculture effluents around the coastal areas in Southwestern Nigeria. It is therefore imperative that aquaculture effluents are properly managed to prevent environmental pollution.

Over the years, many end-of-pipe technologies have been investigated as possible treatment options for aquaculture effluents. These technologies range from biological processes such as phytoremediation (Ghaly et al., 2005) and biological filters (Gutierrez-wing and Malone, 2006) to advanced oxidation processes such as solar-driven photocatalytic degradation (Martins et al., 2021). Igwegbe et al., (2022) investigated the treatment of aquaculture effluent using *Picralima nitida seeds* as a coagulant/adsorbent and reported more than 80% reduction in the organic loading of the effluents. Due to the organic constituents of aquaculture effluents, biological processes have been the most widely utilized treatment technologies and many studies have been reported in this regard (Dauda et al., 2019; Turcios and Papenbrock, 2014). Sikder et al., (2016) provided a review of the sustainable treatment of aquaculture effluents, focusing on biological processes. In a recent review, Ogunfowora et al., (2021) provided an overview of the trends in the treatment of aquaculture effluents using nanotechnology.

Despite these studies, however, there is yet to be a comprehensive study that focuses on the dynamics of the aquaculture ecosystem, including the temporal variations of the physicochemical parameters of the pond water. The complex interactions between fish feeds, antibiotics, metabolites, and the intrinsic chemical compounds from the water sources result in temporal variations of the water quality parameters. Information on these variations is necessary for proper management of aquaculture ponds, including scheduling water discharge and disposal. Understanding these dynamics would also be useful for the potential utilization of the effluents as irrigation water. Despite the significance of these aspects, they have not received wide attention and are therefore scarcely reported in the literature. In this regard, the main objective of this work is to evaluate the temporal dynamics of the physicochemical properties of aquaculture pond water with a view to its sustainable management and utilization as irrigation water.

MATERIALS AND METHODS

Study Location

This study was conducted at the Training and Research Farm of the Centre for Dryland Agriculture (CDA), Bayero University Kano. The Centre has an aquaculture unit comprising eight (8) ponds with capacities to accommodate over 16,000 fish (Fig 1).

Figure 1: Arial view of CDA Farm fish ponds

Evaluating the temporal variation of the physicochemical properties of aquaculture pond water

The temporal variations of the physicochemical properties of the water were evaluated by collecting samples from the fish pond daily for thirty (30) days, which corresponds to the maximum time the fish farmers take to change their pond water in the study area. The samples collected were analyzed in the laboratory to assess the temporal variation in the physicochemical characteristics of the water in the fish ponds. For each sampling campaign, grab samples were collected using 1 L plastic containers that had been previously washed. Laboratory analyses were conducted at the CDA Laboratory. The following parameters were analyzed: pH, Electrical Conductivity (EC) µS/cm, Total Dissolved Solids (TDS) mg/L, SAR, Na^+, Mg^{2+}, Ca^{2+}, K^+, heavy metals (Fe, Cu, Zn, Cr, Cd, Pb, etc). The pH, EC and TDS were measured using a JENWAY 3540 pH & Conductivity Meter (Cole-Parmer Ltd, UK). The concentrations of heavy metals were measured using Agilent Microwave Plasma Atomic Emission Spectrometers (MP-AES) (4210 Agilent Technologies). All analyses were performed according to the Standard Methods for the Examinations of Water and Wastewater.

Data Analysis

The data collected was subjected to descriptive analysis, and analysis of variance was conducted to test whether there was a significant difference between the means of the samples collected from the farms. A post hoc test was carried out using Fisher's Least Significance Difference (LSD) to separate means that are statistically different from each other. Measurements of statistical difference were performed at the 5% confidence intervals. All analyses were done using Microsoft Excel and OriginPro 2017.

RESULTS AND DISCUSSION

The temporal dynamics of the physicochemical properties of the aquaculture pond water were studied for thirty (30) days, which is the maximum period for the pond water to be changed based on our previous study in the location (Abubakar, et al 2023). The changes in the physicochemical characteristics of the fish pond water during the 30 days are discussed in this section. These parameters are discussed based on the broad categorization as major cations (crop macro and micro), metals, and irrigation water parameters.

Major Cations

K, Mg, and Ca are among the major nutrients required by plants at high dosages (macronutrients) and are therefore beneficial to plants. However, their presence at high concentrations may affect soil permeability. Although the existing irrigation water quality criteria are based on salinity and the SAR, high concentrations of K, Mg, and Ca in irrigation water may affect soil hydraulic properties. Smith et al., (2015) concluded that the deleterious effect of these cations on soil hydraulic properties is in the following order: K > Mg > Ca. Thus, the concentrations of these cations in irrigation must be assessed.

Figure 2 shows the temporal variation of these elements over the 30-day sampling period. The concentrations of Potassium (K) range from 3.36 mg/L to 5.72 mg/L and it can be seen from Figure 2 that the 10th day recorded the lowest concentration of 3.36 mg/L. In contrast, day 2 recorded the highest concentration of 5.72 mg/L. However, the statistical analysis shows that means in the daily concentrations of K are not significantly different at the 0.05 level (p=0.99). Although the K might be largely from the water source, the fluctuations could be due to feed breakdown, fish metabolism, and hydrodynamics within the pond (Fornari, et al., 2020).

The concentration of Mg in the aquaculture pond fluctuates over the period, with an average of 4.35 mg/L. The concentration of Mg was found to be 4.8 mg/L on the first day, which decreased to 4.24 mg/L by the seventh day. The statistical analysis showed that the differences in the concentration of Mg were not statistically different (p=0.98) over the 30 days. Mg plays a key role in the mechanism and function of chlorophyll in plant tissues. Consequently, its availability will boost plant growth whilst its deficiency will result in poor and stunted plant growth (Gerendas and Fuhrs, 2013). According to FAO, Mg concentrations between 6 and 24 mg/L are desirable in irrigation water. For the samples analyzed over the 30 days, the Mg concentrations are mostly below the lower threshold desirable for irrigation water. Ishfaq, et al (2022) reported that Mg is essential for many important physiological and biochemical processes in plants, with a marked effect on chlorophyll synthesis, as well as the utilization of photoassimilates. Although the availability of Mg for crops is evaluated in the soil, its presence in the aquaculture effluents could be beneficial. However, the availability of the Mg to the crops will largely depend on the soil properties, agronomical practices, climatic variables, and crop species.

Calcium has a higher range of values with the highest value (19 mg/L) on the 5th day and the lowest (12 mg/L) on the 23rd day (Figure 2). However, the daily means concentrations of Ca are not statistically different (p=0.59) at the 0.05 level. Exchangeable calcium improves the physical properties of soils and could combat soil salinity by replacing Na ions (Rangasamy, 1987). Calcium levels below 40 mg/L in the soils are typically considered low. In comparison, high calcium levels above 120 mg/L could be antagonistic, leading to a deficiency in phosphorus and magnesium in irrigation water. Thus, the range of Ca concentrations over the 30 days is on the lower spectrum, but the pond water could still be used as irrigation water. These concentrations are lower than those reported by Bichi and Bello (2013). The concentrations of these cations observed in the pond water are in this order: Ca > Mg > K, which indicates that the water is unlikely to pose any harmful effect on soil hydraulic conductivity and is, therefore, suitable for irrigation.

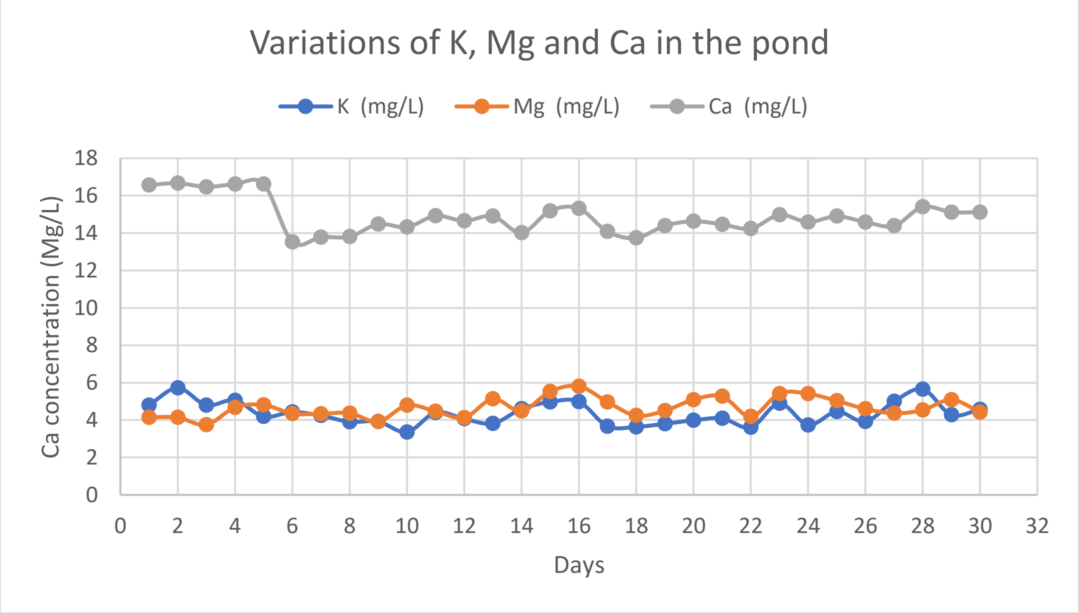

Figure 2: Temporal variation of Potassium, Magnesium and Calcium in the Aquaculture Pond

Metals

The concentrations of Fe in the pond water increased from day 1 but fluctuated over the 30 days monitored (Figure 3). The highest Fe concentration (2.37 mg/L) was observed on day 20 while day 1 recorded the lowest concentration (0.42 mg/L). However, the differences in the daily mean concentrations were not statistically different (p=0.99). High Fe concentrations in irrigation water may cause clogging of drip emitters and rusting of iron structures. Water with Fe concentrations above 0.1 mg/L is considered unsuitable for irrigation due to emitter clogging and foliar spotting (Zinati and Shuai 2005). However, the FAO has recommended a threshold concentration of 5 mg/L for irrigation water (FAO, 1992). This shows that the Fe concentrations over the 30 days are still below the maximum threshold recommended by the FAO, and the pond water is thus suitable for irrigation.

The Zinc (Zn) concentration in the pond water drops from 7.8 mg/L on the 1st day to about 6.5 mg/L on the 5th day (Figure 3). The high concentrations of Zn may have originated from the water source, and the decrease over time could be attributed to the complex interactions within the pond ecosystem, including potential assimilation by the fish. Although the Zn concentrations in the first 5 days are above the FAO recommended threshold of 2.0 mg/L, (FAO, 1992), the final concentrations are below the threshold. Thus, the pond water is unlikely to pose any toxicity issues to crops and is thus, suitable for irrigation.

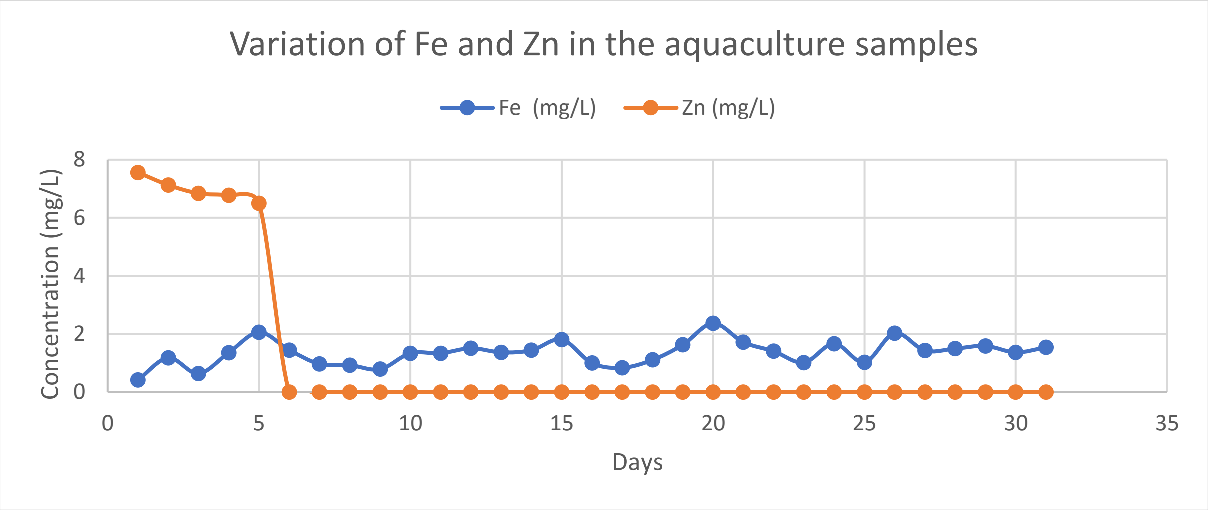

Figure 3: Temporal Variation of Iron and Zinc in the aquaculture pond

The concentrations of Copper (Cu) in the pond water varied widely over the 30 days (Figure 4), but there was no significant difference in the mean concentrations ($p=0.99$). The highest concentration was observed on day 21. However, the lowest concentrations (ca. 0.04 mg/L) were observed around the last 30 days. The concentrations of Cu observed were lower than FAO's maximum recommended concentration of 0.20 mg/L. The variation in the Manganese concentration is shown in Figure 4, and it can be seen that the lowest concentration was observed on day 1. The concentration then fluctuated over the 30 days, with the exit concentration of about 0.02 mg/L. The concentrations of both Cu and Mn observed are below the recommended threshold and thus, the fish pond water is suitable for irrigation as per as these metal ions. The concentrations are also lower than those reported by Bichi and Bello (2013).

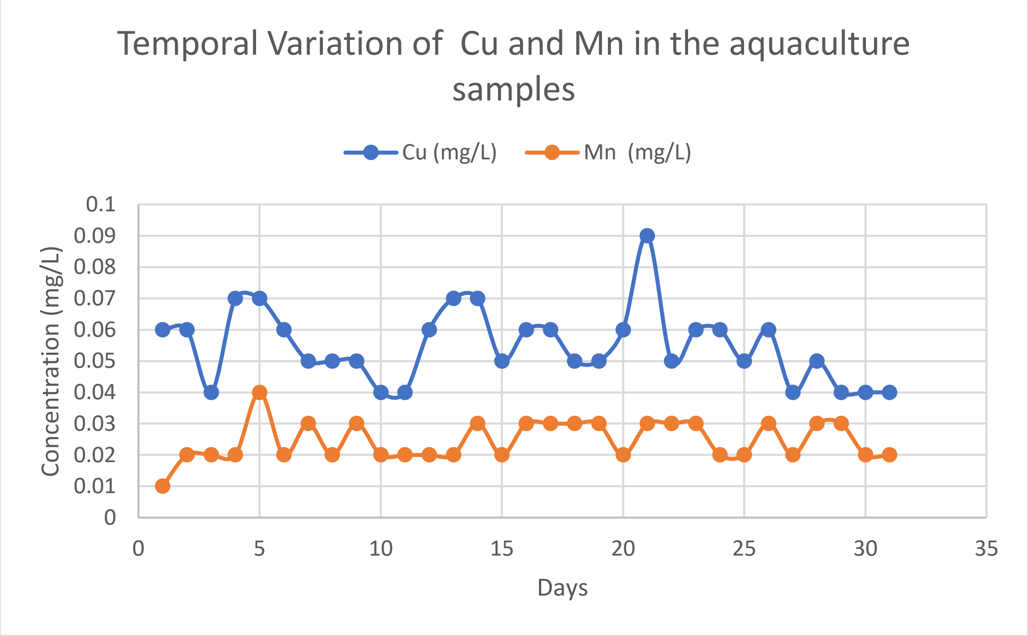

Figure 4: Temporal Variation of Copper and Manganese in the aquaculture pond

Irrigation water parameters

The sodium adsorption ratio (SAR) is an irrigation water quality parameter for assessing sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the major cations of Na, Mg, and Ca present in the water. Figure 5 shows the variation of SAR across the 30 days of sampling and the result shows an increasing trend in the SAR values. The increasing trend in the SAR may be attributed to the complex interactions between these cations, as well as the feeding regime and fish metabolism. Although FAO has recommended SAR values below 3 for irrigation water, SAR values are typically analyzed alongside the EC values. Thus, considering the SAR values and the EC values observed in the samples, the fish pond water will pose a "slight to moderate" restriction when used as irrigation water. This is particularly important when crops that are sensitive to salts are to be irrigated.

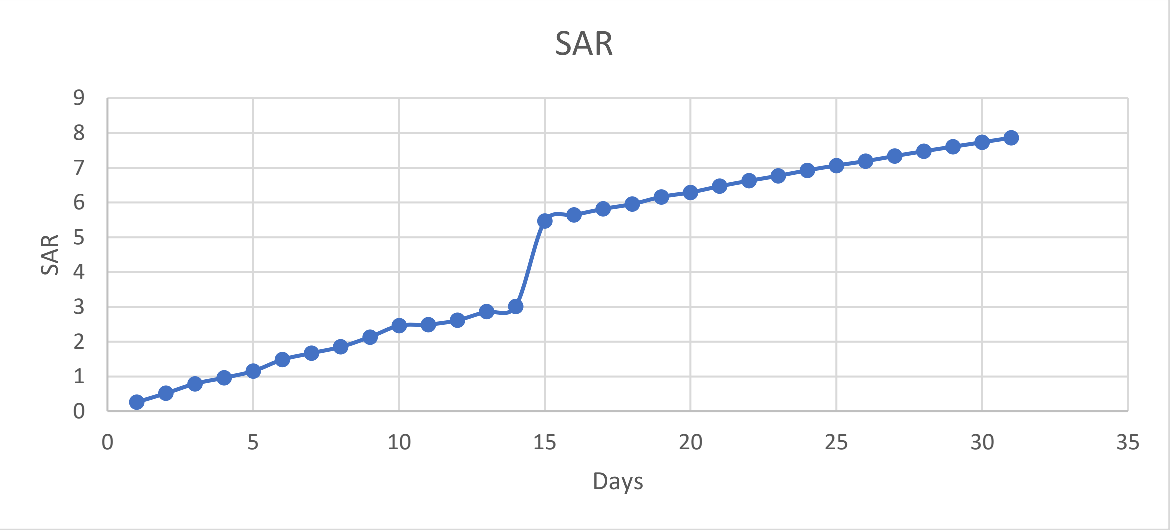

Figure 5: Temporal Variation SAR in the aquaculture pond water

Electrical conductivity (EC) is a measure of electrolytes in the water and represents the total dissolved salts since most salts can be ionized. Water with high EC may be unsuitable for irrigation, depending on the SAR values and the crops to be grown. In this regard, the FAO recommends EC values below 0.7 dS/m for normal irrigation water. EC values above this may pose slight to moderate restrictions (0.7 – 3.0 dS/m) or severe restrictions (3.0 dS/m) for irrigation (FAO, 1995). The EC values of the pond water fluctuated between this study are below 0.7 dS/m, and are, therefore, suitable for irrigation.

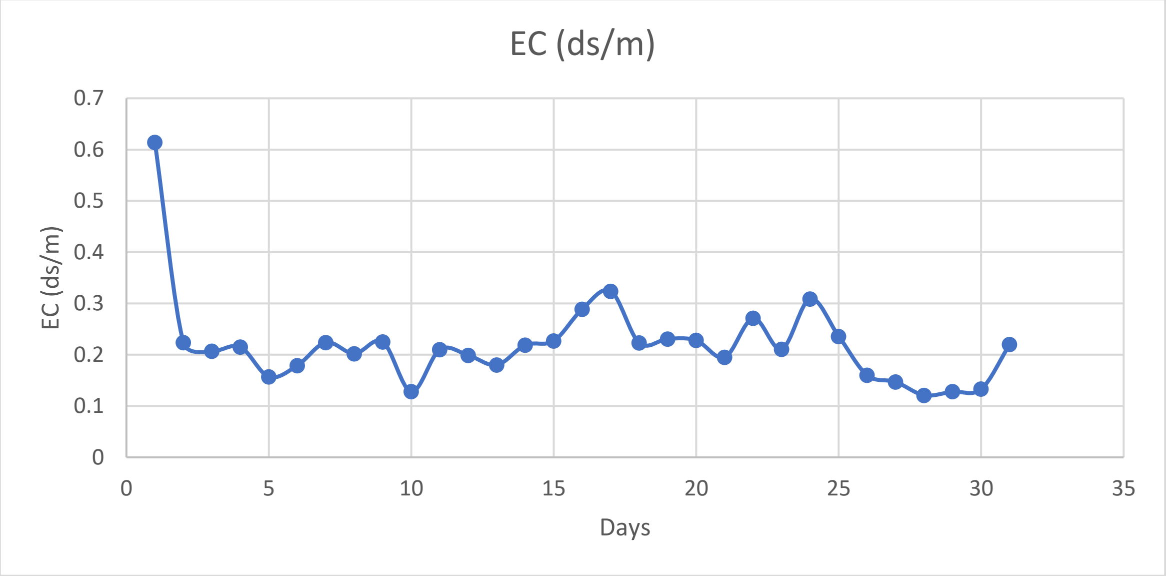

Figure 6: Temporal Variation of Electrical Conductivity (EC) in the aquaculture pond

Figure 7 shows the variation of pH in the fish pond over the study period. The pH values range between 5.77 to 7.34, with the exit pH at 6.31. The pH measures the degree of acidity and alkalinity of the water based on the hydrogen ions. The FAO recommended a pH range between 6.5 to 8 for normal irrigation water. Although the pH falls below this range on some days, it is mostly within the range, indicating that water is suitable for irrigation. The fluctuation in the pH values could be attributed to the ionic interactions within the pond.

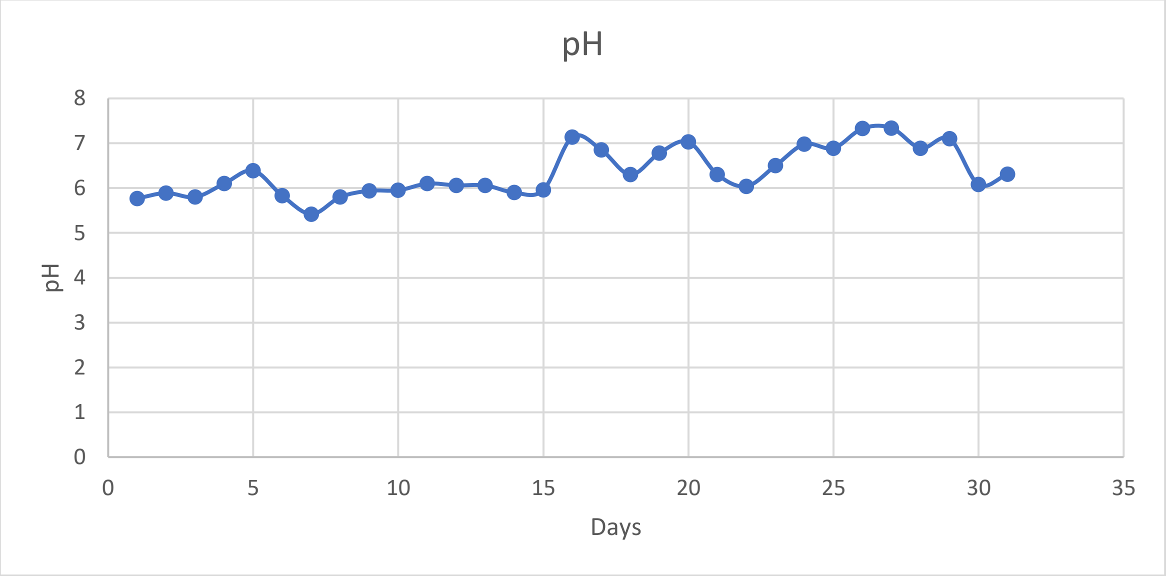

Figure 7: Temporal Variation of pH in the aquaculture pond

CONCLUSION

The temporal dynamics of the physiochemical properties of aquaculture pond water were evaluated in this study. The results showed that the physicochemical parameters fluctuated over the 30 days monitored. Among the major cations, Ca exhibited the highest variation, with the highest concentration (19 mg/L) on the 5th day whilst the lowest (12 mg/L) was observed on the 23rd day. The concentration of Mg fluctuated over the period, with an average of 4.35 mg/L. Overall, the concentrations of these cations in the pond water are in the following order: Ca > Mg > K, which indicates that the water is unlikely to pose any harmful effect on soil hydraulic conductivity and is, therefore, suitable for irrigation. Although the concentrations of some metals varied over the period, the concentrations at the end of the study are below the recommended threshold values for irrigation. Concerning the irrigation water parameter, the SAR analysis showed an increasing trend over the period, with the value exceeding the FAO recommended threshold after the first 14 days. Considering the SAR and EC values, the pond water will pose a "slight to moderate" restriction when used for irrigation. Although the physicochemical parameters of the aquaculture pond water varied over the period investigated, the water could still be used for irrigation but may pose a slight to moderate restriction for salt-sensitive crops.

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