EVALUATION OF NUTRIENT AND HEAVY METAL CONCENTRATIONS IN AQUACULTURE WASTEWATER AND AQUATIC MACROPHYTES (*EICHHORNIA CRASSIPES* AND *PISTIA STRATIOTES*) BEFORE PHYTOREMEDIATION

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ABSTRACT

Aquaculture expansion has increased levels of nutrients and metals in production ponds, making the need for environmentally friendly treatment methods necessary. This study assessed the baseline concentrations of nutrients and metals in aquaculture wastewater and aquatic macrophytes *(Eichhornia crassipes* and *Pistia stratiotes)* before phytoremediation. Samples of wastewater and plants were collected during both dry and wet seasons from aquaculture ponds in Makurdi, Nigeria, and analyzed for physicochemical properties, nutrient content, and metal concentrations. Results revealed seasonal differences in wastewater quality. Calcium (118.3 ± 0.15 mg/L), magnesium (75.22 ± 0.11 mg/L), sodium (63.41 ± 0.12 mg/L), and potassium (32.45 ± 0.08 mg/L) were significantly higher during the dry season ($p < 0.01$), while iron levels were higher in the wet season (6.22 ± 0.01 mg/L; $p < 0.001$). The pH was slightly higher in the wet season (6.43 ± 0.03), whereas turbidity and biochemical oxygen demand were elevated in the dry season (26.26 ± 0.03 NTU and 13.40 ± 0.10 mg/L, respectively). In macrophytes, magnesium concentrations were significantly higher in the wet season for both water hyacinth (14.28 ± 1.30 mg/kg; $p = 0.001$) and water lettuce (15.72 ± 1.10 mg/kg; $p < 0.001$). In contrast, sodium, potassium, and manganese levels were highest during the dry season. These findings highlight the strong influence of seasonal changes on wastewater quality and how metals accumulate in aquatic plants before exposure to treatment conditions. The high metal uptake observed in *E. crassipes* and *P. stratiotes* further supports their potential as effective phytoremediation agents. This study provides useful baseline data that can help improve macrophyte-based wastewater treatment strategies in tropical aquaculture systems.

Keywords: Aquaculture wastewater, eutrophication, metals, water hyacinth, water lettuce, water quality parameters.

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1. | Introduction

The rapid global expansion of aquaculture has played a major role in improving food security, supporting livelihoods, and driving economic growth. As one of the fastest-growing food production sectors, aquaculture accounts for 94.4 million tons of the global fish supply in 2022 (FAO, 2022). However, this growth has also raised environmental concerns, particularly regarding the pollution of water bodies through the discharge of nutrient-rich and metal-containing effluents from aquaculture systems. Intensive fish farming often leads to the buildup of excess nutrients, mainly nitrogen (N) and phosphorus (P), along with metals such as copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), and cadmium (Cd). These pollutants typically originate from uneaten feed, fish waste, prophylactic treatments, and other farm inputs (Boyd and Tucker, 2012; Yi *et al*., 2020). High concentrations of these substances can create serious ecological problems. Excess nutrients can accelerate eutrophication, reduce dissolved oxygen levels, and disrupt aquatic ecosystems, while heavy metals may accumulate in organisms and pose toxicity risks to both aquatic life and humans through the food chain (Li *et al*., 2019; Ogbonna *et al*., 2020). Because of these risks, regular monitoring of nutrient and metal levels in aquaculture wastewater is essential to ensure environmental sustainability and compliance with regulations.

Interest in environmentally friendly wastewater treatment methods has increased, drawing attention to the use of aquatic macrophytes for phytoremediation (Rezania *et al*., 2016).. Water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) are widely distributed floating plants known for their strong ability to absorb and accumulate nutrients and metals from polluted water (Lu *et al*., 2010; Rezania *et al*., 2016). Their rapid growth, extensive root systems, and adaptability to different aquatic environments make them especially useful for treating wastewater from agricultural, municipal, and aquaculture sources.

Although previous studies have examined aquaculture effluent quality and the remediation potential of these plants, there is still a need for region-specific studies that consider seasonal and operational variations. It is also important to determine nutrient and metal concentrations already present in plant tissues (roots and shoots) before they are used in treatment systems. Identifying key pollutants in aquaculture discharge can help guide targeted and eco-friendly treatment strategies, such as phytoremediation. This study therefore focuses on quantifying nutrients and metals in aquaculture wastewater and in *E. crassipes* and *P. stratiotes* collected from their natural environment. The goal is to provide baseline data for environmental assessment and offer insights into effective management and treatment of aquaculture effluents.

2. | Materials and Methods

2.1 | Study Area and Site Description

The study was carried out at the fish farm of Joseph Sarwuan Tarka University, Makurdi, Nigeria. The area lies within the Middle Belt region and experiences a tropical climate with two distinct seasons: the wet season (April to September) and the dry season (October to March).

2.1.1 | Wastewater Collection

Wastewater samples were collected during both seasons to capture variations in nutrient and metal concentrations. Samples were obtained from Oracle Farms Limited, located in the industrial layout of Makurdi. The farm operates an intensive catfish (Clarias gariepinus) production system, where ponds are periodically drained and refilled using borehole water. Water samples were taken from production ponds before discharge, at a depth of about 15-20 cm below the surface, using acid-washed polyethylene bottles. To prevent changes in metal composition, samples for metal analysis were immediately acidified to pH < 2 using ultrapure nitric acid (HNO_3, 65%). All samples were transported in ice-cooled containers and stored at 4°C until analysis.

2.1.2 | Plant Collection and Preparation

Fresh samples of *E. crassipes* and *P. stratiotes* were collected from the banks of River Benue. The plants were separated into roots and shoots, thoroughly rinsed with deionized water to remove dirt and surface particles, and oven-dried at 70°C until a constant weight was achieved. The dried samples were then ground into fine powder using a ceramic mortar and pestle and stored in airtight containers for analysis.

2.1.3 | *Physicochemical Parameter Measurement*

Key water quality parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), turbidity, and temperature were measured using a calibrated multiparameter probe (Hanna HI98129). Biochemical oxygen demand (BOD) was determined using the standard 5-day BOD test (APHA 5210B; APHA, 2017).

2.1.4 |Nutrient Analysis in Wastewater

Nutrient concentrations (nitrate, phosphate, sulfate, and bicarbonate) were analyzed following standard APHA (2017) methods. Nitrate was measured using the cadmium reduction method, phosphate using the ascorbic acid method, sulfate using the turbidimetric method, and bicarbonate using titration. Absorbance readings were taken with a UV-Vis spectrophotometer (UV-2600i Plus).

2.1.5 | Metal Analysis in Wastewater and Plant Tissues

Standard procedures for wastewater and plant tissue analysis were used to determine the concentrations of selected metal ions in wastewater and plant tissues using the acid digestion then Atomic Absorption Spectrophotometry (AAS), based on the standard procedures (AOAC, 2016; APHA, 2017). Metal concentrations (Fe, Zn, Cu, Mn, Ca, Mg, Na, and K) were determined using Atomic Absorption Spectrophotometry (AAS; Buck Scientific Model 205). Samples were first digested with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 3:1 ratio at 95°C until clear solutions were obtained. Quality control was ensured using blanks and certified reference materials, and all analyses were performed in triplicate.

Data were analyzed using independent sample t-tests and descriptive statistics (mean ± SD) to evaluate seasonal differences and determine statistical significance.

3. | Results and Discussion

3.1 | Seasonal Metal Concentrations in Aquatic Macrophytes

Seasonal variations in metal concentrations were observed in both *E. crassipes* and *P. stratiotes*. (Figure 1 and 2) In *E. crassipes*, magnesium levels were significantly higher during the wet season (14.28 ± 1.30 mg/kg) compared to the dry season (5.48 ± 0.29 mg/kg; $p = 0.001$). In contrast, sodium and potassium were higher in the dry season. Manganese levels also decreased significantly during the wet season, while calcium, iron, zinc, and copper showed no notable seasonal changes. A similar pattern was seen in *P. stratiotes*. Calcium levels were higher in the dry season, whereas magnesium increased significantly during the wet season. Potassium decreased in the wet season, while zinc increased. Manganese showed a sharp decline in the wet season, and iron and copper remained relatively stable. These trends suggest that both plants respond strongly to environmental conditions. Higher magnesium uptake in the wet season may be linked to increased nutrient availability and mobility due to rainfall as also reported by Huang *et al*., (2021). Elevated sodium and potassium in the dry season could result from evaporation and reduced water dilution (Nhiwatiwa *et al*., 2022). Changes in manganese may be associated with shifts in redox conditions (Santos *et al*., 2019), while the stability of iron, zinc, and copper reflects the plants' ability to regulate these metals (Abdel-Latif *et al*., 2023). The enhanced Zn uptake by water lettuce during the wet season may be due to improved bioavailability under lower ionic competition, as reported by Rodrigues *et al*. (2020).

3.2 | Seasonal Variation in Metal Concentrations in Aquaculture Wastewater

Metal concentrations in wastewater also varied by season as shown in Figure 3. Calcium, magnesium, sodium, and potassium were consistently higher in the dry season, likely due to evaporation

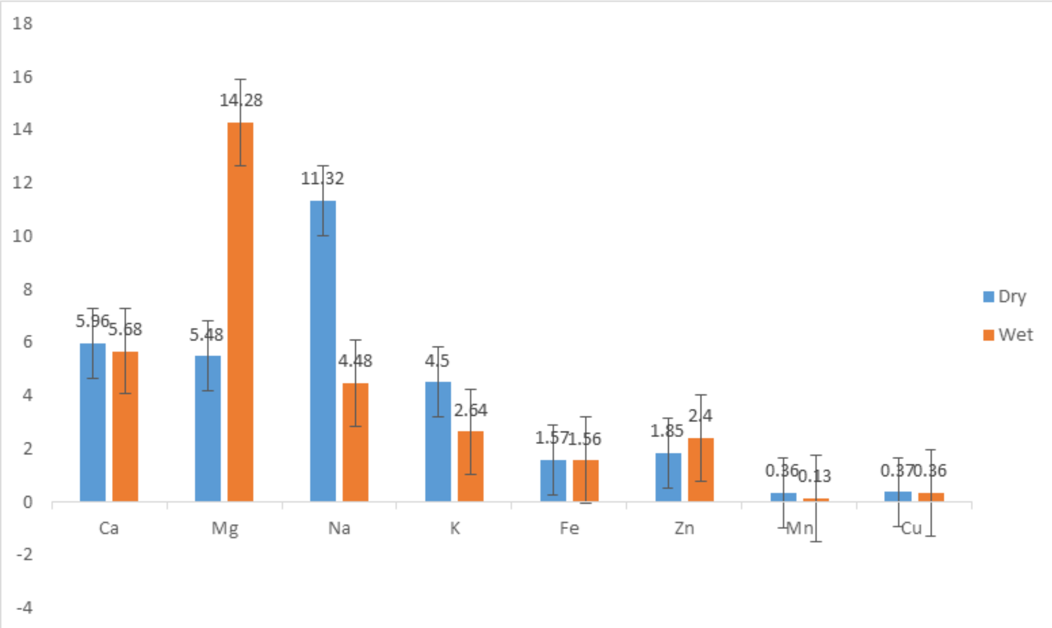

Figure 1 | Metal Concentration in *Eichhornia crassipes* during Dry and Wet Seasons

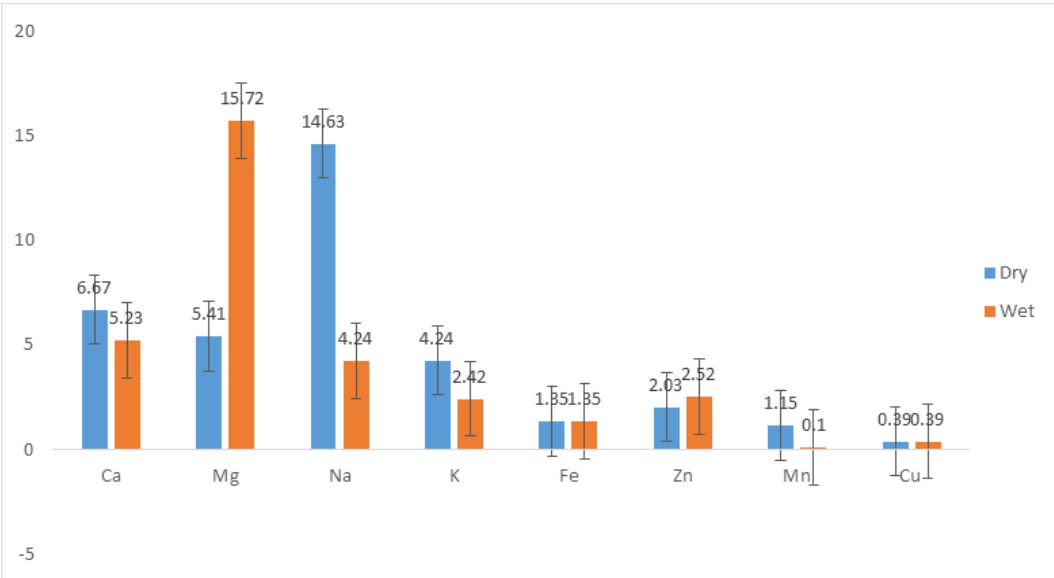

Figure 2 | Metal Concentration in *Pistia stratiotes* during Dry and Wet Seasons

concentrating dissolved substances (Okon *et al.*, 2021). Iron, however, increased during the wet season (6.22 ± 0.01 mg/L, 4.89 ± 0.01 mg/L), likely due to increased runoff, erosion, and accumulation of iron-rich sediments (Mahmud *et al.*, 2022). Zinc levels were higher in the dry season (8.19 ± 0.02 mg/L), while copper decreased significantly during the wet season (1.14 ± 0.01 mg/L). Manganese showed little variation. Lower metal concentrations in the wet season can be attributed to dilution effects and reduced input from feed and infrastructure (Oladipo *et al.*, 2023; Zhang *et al.*, 2021).

3.3 | Seasonal Differences in Physicochemical Parameters

Physicochemical properties of the wastewater also showed seasonal patterns (Figure 4). The pH was slightly higher during the wet season (6.43 ± 0.03),

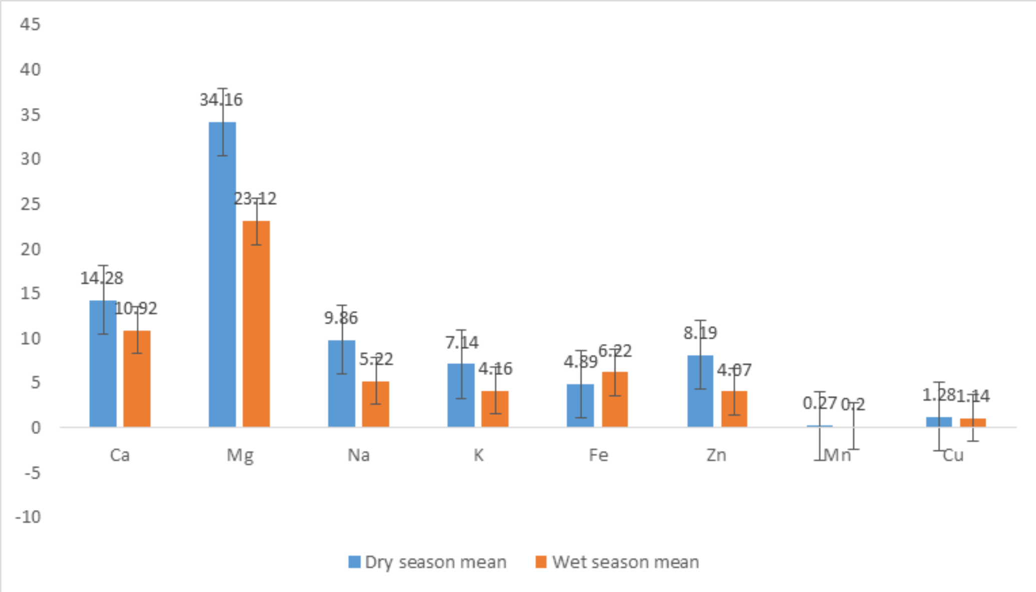

Figure 3 | Metal Concentration in Aquaculture Wastewater during Dry and Wet Seasons

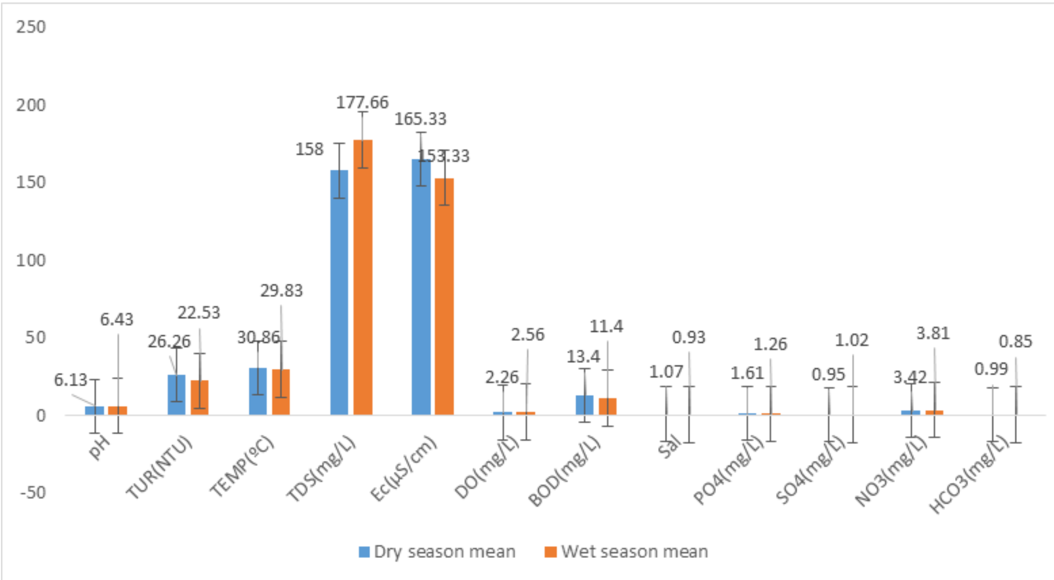

Figure 4 | Physiochemical Parameters of Aquaculture Wastewater during Dry and Wet Seasons

likely due to increased photosynthesis and water movement (Saraswat *et al*., 2022). Turbidity and BOD were higher in the dry season (26.26 ± 0.03 NTU; 13.40 ± 0.10 mg/L respectively), indicating greater organic load from reduced water exchange and more intensive feeding (Tibbetts *et al*., 2018). Total dissolved solids (TDS) were unexpectedly higher in the wet season, possibly due to runoff introducing additional dissolved materials (Semedo *et al*., 2020). Electrical conductivity decreased in the wet season due to dilution, while dissolved oxygen increased slightly, though not significantly. Sulfate levels increased slightly, while phosphate and nitrate remained relatively stable across seasons, suggesting consistent feeding practices (Urbaniak *et al*., 2019). Bicarbonate decreased in the wet season, likely due to dilution and increased carbon uptake by aquatic organisms (Perkins *et al*., 2020).

These seasonal trends highlight the strong influence of environmental conditions on water quality and metal behavior. Both water hyacinth and water lettuce demonstrated effective metal accumulation across seasons, supporting their use in phytoremediation. Improved uptake of certain metals during the wet season suggests that treatment systems using these plants may perform better under high-flow, nutrient-rich conditions (Kaur and Das, 2023; Rezania *et al*., 2022). Understanding these seasonal patterns is essential for designing year-round treatment strategies, optimizing harvesting schedules, and predicting phytoremediation performance.

4. | Conclusion

This study shows that seasonal changes such as evaporation and plant species both play important roles in determining nutrient and metal levels in aquaculture wastewater and aquatic plants before phytoremediation. Metal concentrations varied across seasons, with higher accumulation generally observed in the dry season, while the wet season supported greater availability of certain elements like magnesium and iron. Physicochemical parameters also changed with season, reflecting the dynamic nature of aquaculture environments. The ability of *E. crassipes* and *P. stratiotes* to accumulate metals even before controlled treatment confirms their value as effective and environmentally friendly options for wastewater management. These findings provide important baseline data that can support better monitoring, improved treatment design, and more sustainable aquaculture practices.

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