



Sustainable water circularity using electrocoagulation system for *Leptobarbus Hoevenii* aquaculture wastewater treatment in rural Borneo

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ABSTRACT

A rapid expansion of freshwater fish farming has led to mounting environmental and water resource challenges in Southern Sarawak which is also a major aquaculture hub on Borneo Island. As such, this study aims to investigate the effectiveness of an electrocoagulation system using aluminium electrodes for *Leptobarbus Hoevenii* aquaculture wastewater treatment by treating it into safe and economical reusable water source for fish farming operations in the tropical rural southern Sarawak region. Subsequent, this study has found the operation of electrocoagulation system at 20 V of applied voltage, 5 A of electric current, and 50 min of residence time could achieve high contaminant reduction efficiency with up to 98.74% for colour, 91.63% for turbidity, and over 95% for TOC and TSS. In this study, the treated aquaculture wastewater has met all Class II criteria under Malaysia National Water Quality Standards which indicates its suitability for safe environmental discharge or reuse in *Leptobarbus Hoevenii* production ponds. Additionally, the treatment of such water source cost only RM 3.98/m³ (USD 0.90/m³) which indicates the electrocoagulation system as a cost-effective system. The electrocoagulation process could also process produced Al(OH)₃-rich flocs by containing 32.29% aluminium and 53.57% oxygen which effectively removed 90% of contaminants while concentrating several nutrients, specifically 2.85% nitrogen, 0.38% phosphorus, and 0.47% potassium. Overall, this study has demonstrated that the electrocoagulation treatment system offers an effective approach for transforming *Leptobarbus Hoevenii* aquaculture wastewater into a safe and sustainable water source for reuse in fish farming operation across the tropical Borneo region.

1. Introduction

Aquaculture has emerged as one of the most rapidly expanding sectors in global food production which plays a crucial role in meeting the increasing demand for fish protein among a growing world population (Boyd et al., 2022). According to the projection by Food and Agricultural Organization (2025), aquaculture industry is expected to supply over 50% of the world fish consumption by 2030. As added by

Stenson and Creedon (2022), this remarkable growth is driven by factors such as overfishing of wild stocks, increasing demand for seafood as well as the recognition of aquaculture potential in contributing to sustainable food system. However, the intensification of fish farming activities exerts considerable pressure on aquatic ecosystems, especially in tropical regions (Mugwanya et al., 2022). In these regions, warm temperatures could accelerate metabolic rates as well as decomposition processes (Islam et al., 2022). Additionally, nutrient rich effluents from

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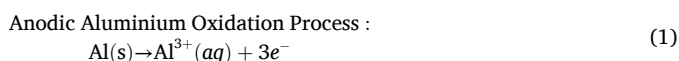
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aquaculture facilities could enhance ecological degradation through mechanisms such as eutrophication. A study conducted by [Ahmad et al. \(2022\)](#) reported eutrophication could lead to algal blooms which devastate aquatic biodiversity and disrupt ecosystem services. This signifies aquaculture industry presents the environmental sustainability challenges despite offering mitigation plan to food security challenges. As reported by [Tom et al. \(2021\)](#), wastewater management in aquaculture is a critical component in mitigating environmental risks associated with fish farming. This is due to the fact aquaculture effluents are typically constituted with organic matter and suspended solids which could have adverse effects on receiving water bodies if discharged untreated ([Iber et al., 2023](#)).

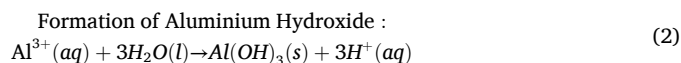
Southern Sarawak that located on Borneo Island in Malaysia exemplifies a region where aquaculture plays a significant socio-economic role. According to [Harun et al. \(2024\)](#), the region is renowned for the farming of *Leptobarbus hoevenii* or commonly known as the Sultan Fish. The growth of *Leptobarbus hoevenii* aquaculture has provided economic opportunities for small-scale farmers and has become an integral part of the local economy. Despite these benefits, the rapid expansion of aquaculture in southern Sarawak presents substantial environmental sustainability challenges. One of the most pressing concerns is the direct discharge of untreated aquaculture wastewater into nearby waterways which including rivers and coastal areas. These practices have led to the accumulation of pollutants such as organic matter, nutrients, and suspended solids to the environment. As reported by [Hejazy et al. \(2023\)](#), high levels of nutrients in the effluent could promote eutrophication which resulting in harmful algal blooms, oxygen depletion, and the loss of biodiversity. In addition to wastewater discharge issues, aquaculture operations in southern Sarawak face challenges related to water supply for maintain fishponds. This is due to the tropical climate in such regions is characterized by seasonal rainfall patterns in which some fish farmers rely heavily on rainwater to fill and maintain their aquaculture ponds. Moreover, the unpredictability of rainfall patterns due to climate change has made this reliance unsustainable. The over reliance on rainwater also makes aquaculture vulnerable to fluctuations in water availability which could result in reduced yields or total crop failures. Realizing these issues, there is an urgent need to develop sustainable water management practices for aquaculture in southern Sarawak.

Although conventional wastewater treatment methods such as activated sludge system and membrane filtration technologies are effective for contaminants removal from water sources, such systems are often too expensive or technically complex for small-scale fish farmer to implement ([Tom et al., 2021](#)). As added by [Ojewole et al. \(2024\)](#), these systems require high capital investment, specialized equipment, and technical expertise for operation and maintenance which are typically beyond the means of smallholder aquaculture operators in developing regions. Realizing these challenges, electrocoagulation has emerged as a promising alternative for wastewater aquaculture systems by offering potential solution to the problems faced by small-scale fish farmers. Electrocoagulation is a process that utilizes electrical currents to remove contaminants from water sources through mechanisms involving coagulation, adsorption, flocculation and floatation ([Akhter et al., 2021](#)). The process also involves dissolution of sacrificial anodes which typically made of aluminium metals. At the anode, aluminium metal undergoes oxidation that releasing electrons and forming aluminium ions as shown by Equation (1) ([Abdul Rahman et al., 2023a, b](#)). The generated Al^{3+} species then participate in rapid hydrolysis and stepwise complexation reactions, leading to the formation of monomeric and polymeric aluminium hydroxo species that ultimately govern coagulant generation and surface passivation behaviour in the system.



The aluminium ions produced at the anode will react with water molecules in the water sources which leading to the formation of aluminium hydroxide precipitates, as shown by Equation (2) ([Abdul](#)

[Rahman et al., 2024a,b](#)).



In hydrolytic conversion of aluminium ions to aluminium hydroxide, aluminium ions interact with water in order to generate in-situ aluminium hydroxide coagulants. Following anodic dissolution, the released Al^{3+} ions undergo hydrolytic speciation in water, where coordinated water molecules are progressively deprotonated, resulting in the formation of insoluble aluminium hydroxide precipitates, $Al(OH)_3(s)$, together with the liberation of H^{+} into the aqueous medium. This precipitation step is mechanically important because the freshly formed amorphous $Al(OH)_3$ flocs provide highly reactive adsorption and sweep-coagulation sites for contaminant destabilization, while the concurrent proton generation can locally suppress pH and influence the overall hydrolysis equilibrium. Furthermore, the utilization of aluminium electrodes in electrocoagulation has been reported effective in removing various contaminants such as suspended solids, nutrients, and organic matter from wastewater. This is due to the fact aluminium ions are released to form hydroxides that act as in-situ coagulant which subsequently aggregating suspended particles and dissolved contaminants into larger electrocoagulation flocs ([Abdul Rahman et al., 2025a,b](#)). Additionally, electrocoagulation has the advantage of producing less sludge compared to chemical coagulation methods. This suggests electrocoagulation systems are relatively simple to operate, reduce burden of sludge management, require less than space than conventional treatment systems, and could be scaled down to suit the needs of small-scale operations ([Akhter et al., 2021](#); [Ingelsson et al., 2020](#)).

Despite its potential benefits, the utilization of electrocoagulation in tropical aquaculture systems, especially for species such as *Leptobarbus hoevenii* is yet to be reported in the published literature. Most studies on electrocoagulation have focused on treating natural water sources ([Abdul Rahman et al., 2025a,b](#)) and industrial effluents ([Nasrullah et al., 2022](#)), with limited study on aquaculture in tropical context. This is due to the fact that the extensive work on voltage and electric current optimization in electrocoagulation treatment system has largely targeted industrial, municipal, or synthetic wastewater sources ([Jasim et al., 2023](#); [Akhter et al., 2021](#)). Although operating between 10 V and 20 V, or at currents ranging from 8 to 25 mA/cm², these conditions could not be assumed to achieve the simultaneous organic contaminants reduction needed to forestall eutrophication in aquaculture wastewater sources. According to [Vamsi Nagaraju and Sunil \(2024\)](#), tropical aquaculture wastewater presents unique challenges due to higher organic loads and temperatures that could influence the effectiveness of treatment process. Wastewater from *Leptobarbus hoevenii* aquaculture exhibits high levels of colour, turbidity, total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), and total organic carbon (TOC), all of which contribute to environmental degradation if not properly managed ([Liu et al., 2025](#)). Additionally, the absence of long run energy consumption and electrode durability data leaves the true cost-effectiveness of electrocoagulation system remains unclear for smallholder ponds that operate with intermittent power and minimal equipment ([Muchlis et al., 2021](#); [Nasrullah et al., 2022](#)). These unresolved knowledge gaps constrain the development of robust process models and design guidelines, thus, delaying upscaling of electrocoagulation from promising bench studies to reliable as well as field deployable systems for wastewater treatment ([Gasmi et al., 2022](#); [Mousazadeh et al., 2023](#)).

Despite recent progress in aquaculture wastewater treatment, several important gaps remain in the current literature. Several review studies have broadly discussed treatment technologies, sustainability, and circular economy potential, but did not provide a validated and site-specific treatment framework for rural freshwater aquaculture wastewater reuse ([Ahmad et al., 2022](#); [Kashem et al., 2023](#); [Ben-Asher et al., 2024](#)). Furthermore, recent experimental studies have also shown