Jurnal Akta Kimia Indonesia
INDONESIA CHIMICA ACTA

PAPER

View Article Online
View Journal View Issue

**Cite this:** *Indo. Chim. Acta.*, 2025, **18**, **1**.

**Received Date:**
29th April, 2025
**Accepted Date:**
20th June, 2025

**Keywords:**
Phytoremediation;
Salvinia molesta;
Copper;
UV-Vis Spectrophotometer;

**DOI:**
http://dx.doi.org/10.70561/ica.v18i1.43963

# Effectiveness of Kiambang Plant (*Salvinia molesta*) in Phytoremediation of Copper (Cu) Heavy Metal at Various Concentrations

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**Abstract.** This study aimed to determine the effectiveness of the kiambang plant (*Salvinia molesta*) in reducing copper (Cu) heavy metal concentrations in water bodies through phytoremediation. Copper concentrations of 3 ppm, 6 ppm, 9 ppm, 12 ppm, and 15 ppm were applied, and observations were conducted over seven days using a UV-Vis spectrophotometer at a wavelength of 445 nm. The results showed a significant effect of Cu concentration variation on the plant's phytoremediation capacity, as indicated by the One Way ANOVA test (F-count 73.064 > F-table 3.05; $p < 0.05$). The highest remediation efficiency was observed at the 3 ppm concentration, with a removal rate of 91.4% after seven days of treatment. Kiambang plants proved effective as phytoremediation agents in mitigating copper heavy metal pollution in aquatic environments.

## Introduction

Water pollution is an environmental problem caused by the entry of harmful substances into water bodies, which can lead to ecosystem degradation and pose threats to human health. According to Government Regulation Number 22 of 2021, water pollution is defined as the introduction of living organisms, chemicals, energy, or other components into water sources that degrade water quality and prevent their proper use (Farhan et al., 2023). One of the primary pollutants in aquatic environments is heavy metals, such as copper (Cu), which, although essential for biological metabolism, can be toxic when accumulated excessively (Lindawati & Nofitasari, 2021).

Copper contamination in aquatic systems often originates from industrial discharges, mining activities, and agricultural pesticide usage. Elevated copper levels in water can lead to bioaccumulation in aquatic organisms, which subsequently enter the food chain and impact human health (Mentari et al., 2022). High copper exposure may cause organ damage, nervous system disorders, and chronic diseases. Therefore, reducing heavy metal concentrations in water bodies are critical for environmental and public health.

Various wastewater treatment technologies have been developed to address heavy metal contamination, one of which is phytoremediation. Phytoremediation utilizes plants to absorb, accumulate, or degrade pollutants from contaminated water or soil (Rahmawan & Effendi, 2019). This technology offers a low-cost, environmentally friendly solution and can be implemented on-site, making it advantageous compared to conventional methods.

The kiambang plant (*Salvinia molesta*) was selected in this study as a phytoremediation agent due to its high heavy metal hyperaccumulation capacity, rapid growth rate, and wide adaptability to different aquatic conditions (Maryana et al., 2020). Its morphological structure, with floating leaves and dense fibrous roots, facilitates the absorption of heavy metal ions. Additionally, the production of phytochelatin compounds within the plant tissues aids in the detoxification of metal ions, including copper (Nisa, 2023).

Previous studies have demonstrated the effectiveness of kiambang in removing heavy metals such as cadmium (Cd) and lead (Pb) from aqueous media (Baroroh et al., 2018).

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However, studies focusing on its ability to remediate copper (Cu) are still limited, particularly regarding the influence of different metal concentrations on absorption efficiency.

Based on these considerations, this study aims to investigate the effect of varying copper (Cu) concentrations on the phytoremediation capacity of kiambang (*Salvinia molesta*) and evaluate the plant's effectiveness in reducing copper concentrations from contaminated water.

## Experimental

### Material and Methods

The materials used in this study included water fern (*Salvinia molesta*) obtained from natural freshwater ecosystems in Indralaya, South Sumatra. Copper(II) sulfate pentahydrate ($CuSO_4·5H_2O$, Merck, analytical grade) was used to prepare copper solutions. Sodium diethyldithiocarbamate (Na-DDTK, Merck, pro analysis grade) and ammonium hydroxide ($NH_4OH$, Merck, p.a.) were utilized for the complexation process. Distilled water was used for all solution preparations.

Instrumentation included a UV-Visible spectrophotometer (Shimadzu UV-1800, Japan), analytical balance (Ohaus PA214, USA), oven (Memmert UN110, Germany), and standard laboratory glassware (beakers, Erlenmeyer flasks, volumetric flasks, pipettes, and measuring cylinders).

### Procedures

### Sample Preparation

*Salvinia molesta* plants were carefully washed with distilled water to remove debris and then acclimatized in aerated distilled water for 7 days at ambient laboratory conditions (27±2°C, natural light exposure) to stabilize their physiological state before exposure to copper solutions (Norma et al., 2016).

### Preparation of Copper Solutions

A 1000 ppm stock solution of $Cu^{2+}$ was prepared by dissolving 3.929 g of $CuSO_4·5H_2O$ into 1 L of distilled water. Working solutions of 3 ppm, 6 ppm, 9 ppm, 12 ppm, and 15 ppm were subsequently prepared by serial dilution using distilled water according to the procedure described by Pambudi and Suprapto (2019).

### Phytoremediation Procedure

Each treatment involved 500 mL of copper solution placed into separate sterile plastic containers. Ten grams (fresh weight) of acclimatized *Salvinia molesta* were introduced into each container. Experiments were carried out in triplicates for each concentration. Plants were exposed to the copper solution for 7 days under controlled laboratory conditions, with light aeration. Water samples (5 mL) were collected every 2 days (Day 0, Day 2, Day 4, Day 6) to monitor the concentration of $Cu^{2+}$.

### Complexation and Measurement

Water samples were reacted with Na-DDTK 1% and $NH_4OH$ 5% to form Cu-DDTK complexes. The absorbance of the complexes was measured using a UV-Vis spectrophotometer at the maximum wavelength determined at 445 nm. Prior to sample measurement, the maximum wavelength was identified by scanning the standard copper solution within a range of 400–600 nm (Mentari et al., 2022).

### Data Analysis

Absorbance data were used to calculate the remaining copper concentration based on the calibration curve obtained from the standard Cu solutions. The removal efficiency was calculated based on initial and final concentrations. Statistical analyses included Shapiro-Wilk normality test, Levene's homogeneity test, and One Way ANOVA to determine significant differences among treatments at a 5% significance level. Significant differences were further evaluated using the Least Significant Difference (LSD) post-hoc test (Hair et al., 2014).

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C_t}{C_0} \times 100\% \qquad (1)$$

Description:
$C_0$ : Initial concentration of copper (ppm)
$C_t$ : copper concentration at time t (ppm)

## Result and Discussion

### Determination of Maximum Wavelength

The determination of the maximum wavelength was performed to identify the optimal wavelength for the Cu-DDTK complex analysis. Scanning was conducted in the range of 380–700 nm using a UV-Visible spectrophotometer. Based on the scanning results, the Cu-DDTK complex exhibited the highest absorbance at a wavelength of 445 nm. This wavelength was selected for all subsequent measurements because it corresponds to the maximum energy absorption, providing greater sensitivity and accuracy during the analysis.

Using the maximum absorbance wavelength ensures that minor variations in concentration can be detected more reliably. Therefore, 445 nm was chosen as the analytical wavelength for measuring the copper concentration in the samples throughout the study (Pratiwi, 2020).

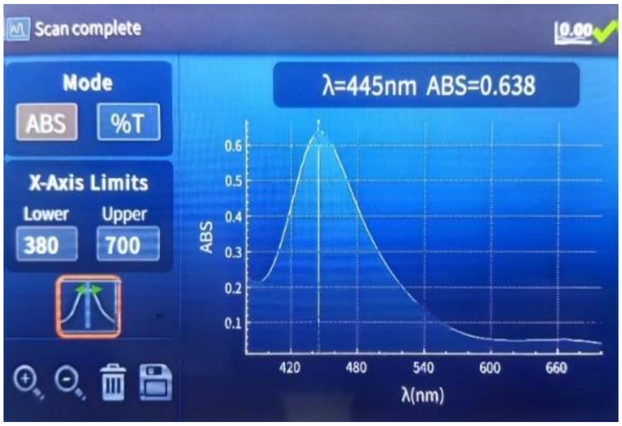


**Figure 1.** UV-Vis spectrum of Cu-DDTK complex showing maximum absorbance at 445 nm.

### Calibration Curve Analysis

The calibration curve was constructed to determine the linear relationship between the concentration of $Cu^{2+}$ ions and the absorbance of the Cu-DDTK complex at a wavelength of 445 nm. The absorbance measurements at various standard concentrations (3, 6, 9, 12, and 15 ppm) are presented in Table 1. Based on these data, a linear regression equation was obtained: $y = 0.0074x + 0.0441$, with an $R^2$ value of 0.9926. This indicates a strong linear relationship between $Cu^{2+}$ concentration and absorbance of the Cu-DDTK complex, validating the method for quantitative analysis.

**Table 1.** Absorbance of $Cu^{2+}$ standard solutions.

| Concentration (ppm) | Absorbance |
|---|---|
| 3 | 0,065 |
| 6 | 0,087 |
| 9 | 0,116 |
| 12 | 0,134 |
| 15 | 0,153 |

The coefficient of determination ($R^2$=0.9926) indicates a very strong linearity, suggesting that this method is highly accurate for the quantitative determination of $Cu^{2+}$ ions. with 5% and 10% bentonite meet the required standard.

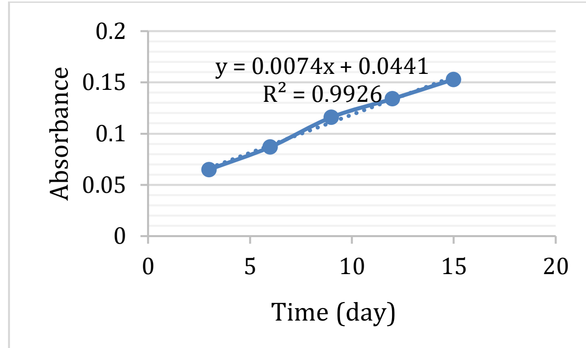


**Figure 2.** Calibration curve between $Cu^{2+}$ concentration and absorbance of the Cu-DDTK complex.

The visualization of this linear relationship is shown in Figure 2, which displays the calibration curve plotting $Cu^{2+}$ concentration against the absorbance of the Cu-DDTK complex. The graph clearly illustrates that the increase in $Cu^{2+}$ concentration corresponds proportionally to the increase in absorbance.

### Copper Concentration in Water Samples During Phytoremediation

The decrease in copper concentration during phytoremediation by *Salvinia molesta* was recorded on days 1, 3, 5, and 7. The concentrations were calculated based on the standard calibration curve.

**Table 2.** Copper concentration (ppm) in samples during phytoremediation.

| Initial Concentration | Day 1 | Day 3 | Day 5 | Day 7 |
|---|---|---|---|---|
| 3 ppm | 2,554 | 1,472 | 0,797 | 0,256 |
| 6 ppm | 5,256 | 3,770 | 2,959 | 2,148 |
| 9 ppm | 8,229 | 7,283 | 6,337 | 5,391 |
| 12 ppm | 11,202 | 10,121 | 9,310 | 8,770 |
| 15 ppm | 14,175 | 13,229 | 12,418 | 12,283 |

The copper concentration decreased at all initial concentrations, with a greater reduction observed at lower initial concentrations.

### Phytoremediation Efficiency of *Salvinia molesta*

The efficiency of phytoremediation by *Salvinia molesta* in reducing copper ion concentrations at various initial concentrations is shown in Table 3 and Figure 3. The data indicate that the percentage removal of $Cu^{2+}$ was highest at lower initial concentrations and decreased as the concentration increased.

At an initial concentration of 3 ppm, *Salvinia molesta* achieved a $Cu^{2+}$ removal efficiency of 91.4% after 7 days. For 6 ppm, the efficiency decreased to 64.2%, and at 9 ppm, it dropped further to 40.1%. Meanwhile, at 12 ppm and 15 ppm, the removal efficiencies were 26.9% and 18.1%, respectively. This trend suggests that *Salvinia molesta* is more effective at lower contaminant levels, where the plant can manage metal uptake without experiencing severe physiological stress.

The decreased efficiency at higher concentrations may be attributed to toxic effects caused by the accumulation of heavy metals in plant tissues, which can impair plant growth and reduce the plant's phytoremediation ability (Baroroh, 2018). Plants experiencing metal stress often exhibit reduced photosynthesis and nutrient uptake (Djo, 2017).

**Table 3.** Phytoremediation efficiency of *Salvinia molesta* at various $Cu^{2+}$ concentrations.

| Initial Concentration | Day 1 (%) | Day 3 (%) | Day 5 (%) | Day 7 (%) |
|---|---|---|---|---|
| 3 ppm | 14,8 | 50,9 | 73,4 | 91,4 |
| 6 ppm | 12,4 | 37,1 | 50,6 | 64,2 |
| 9 ppm | 8,5 | 19 | 29,5 | 40,1 |
| 12 ppm | 6,6 | 15,6 | 22,4 | 26,9 |
| 15 ppm | 5,5 | 11,8 | 17,2 | 18,1 |

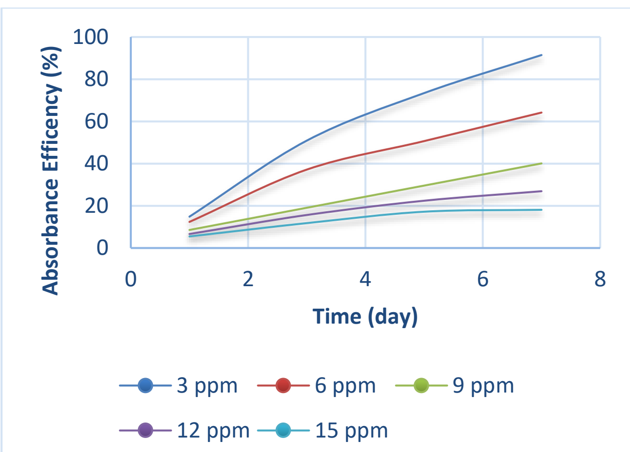


**Figure 3.** Phytoremediation efficiency of *Salvinia molesta* over 7 days at different $Cu^{2+}$ concentrations.

### Statistical analysis of phytoremediation performance

To assess the significance of copper concentration reduction across different treatment levels, statistical tests were conducted, including normality, homogeneity, and ANOVA followed by Least Significant Difference (LSD) post-hoc analysis.

*Normality test*. Shapiro–Wilk test was applied to verify whether the data were normally distributed. The p-values for all treatment groups were greater than 0.05, indicating that the assumption of normal distribution was met.

**Table 4.** Shapiro–Wilk normality test results.

| Initial $Cu^{2+}$ Concentration | Statistic | p-value |
|---|---|---|
| 3 ppm | 0,973 | 0,859 |
| 6 ppm | 0,978 | 0,890 |
| 9 ppm | 0,993 | 0,972 |
| 12 ppm | 0,971 | 0,850 |
| 15 ppm | 0,902 | 0,442 |

All groups yielded $p > 0.05$, confirming the normality of data distribution.

*Homogeneity Test.* Levene's test was used to evaluate the homogeneity of variances across treatment groups. The p-value was 0.912, indicating that the data variances were homogeneous.

**Table 5.** Levene's homogeneity of variance test.

| Levene Statistic | df1 | Df2 | p-value |
|---|---|---|---|
| 0,239 | 4 | 15 | 0,912 |

Since $p > 0.05$, homogeneity of variance assumption was satisfied.

*One-way ANOVA*. One-way ANOVA was conducted to determine the effect of initial $Cu^{2+}$ concentration on phytoremediation performance. A significant difference was observed ($p < 0.05$), indicating that the variations in $Cu^{2+}$ reduction were significantly affected by initial concentration.

**Table 6.** One-way ANOVA results.

| Source | Sum of Squares | df | Mean Square | F | p-value |
|---|---|---|---|---|---|
| Between Groups | 0,020 | 4 | 0,005 | 73,064 | 0,000 |
| Within Groups | 0,001 | 15 | 0,000 | | |
| Total | 0,021 | 19 | | | |

The result of the one-way ANOVA showed that the calculated F-value (F-count = 73.064) was significantly higher than the critical F-table value (F-table = 3.05) at $\alpha$ = 0.05. This indicates that the variation in initial $Cu^{2+}$ concentrations had a statistically significant effect on the phytoremediation efficiency ($p < 0.05$).

*LSD (Least Significant Difference) Test*. Post-hoc LSD test identified which specific treatments differed from each other. Each group received a letter notation based on mean differences. Different letters indicate statistically significant differences.

**Table 7.** LSD post-hoc test results.

| Treatment Group | Mean $Cu^{2+}$ (ppm) | Notation |
|---|---|---|
| 3 ppm | 0,0535 | A |
| 6 ppm | 0,0703 | B |
| 9 ppm | 0,0945 | C |
| 12 ppm | 0,1170 | D |
| 15 ppm | 0,1405 | E |

The result indicates that all treatments were significantly different in their ability to reduce $Cu^{2+}$ concentration.

## Conclusion

This study demonstrated that *Salvinia molesta* is effective in reducing copper ($Cu^{2+}$) concentrations in water through phytoremediation. The highest removal efficiency was observed at 3 ppm with a rate of 91.4% after 7 days. As the initial concentration of $Cu^{2+}$ increased, the phytoremediation efficiency decreased, indicating that the plant performs optimally at lower contaminant levels. Statistical analysis confirmed that the variation in $Cu^{2+}$ concentration significantly affected the plant's remediation performance ($p < 0.05$). These findings support the potential use of *Salvinia molesta* as an eco-friendly phytoremediation agent for treating Cu-contaminated waters.

## Conflict of Interest

The authors declare that there is no conflict of interest.

## Acknowledgements

The authors would like to express their sincere gratitude to the Faculty of Teacher Training and Education (FKIP), Universitas Sriwijaya, for providing the facilities and support necessary for the completion of this research. The authors also extend their appreciation to all laboratory staff and colleagues who assisted during the experimental work.

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