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Potency *Nannochloropsis sp.* As An Agent Bioremediation of Lead Heavy Metal (Pb) In Rivers Jenes

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Abstract: The study aims to test the bioremediation potential of Nannochloropsis sp. against Pb (lead) contamination in the batik textile industrial area. The steps in this study include collecting river water samples from 3 different stations, preparing the samples by adding HNO3, culturing Nannochloropsis sp. seed for 7 days, testing the initial Pb metal content before and after treatment with Nannochloropsis sp. using wet-digestion techniques, and analyzing the samples. The water samples were taken from upstream, midstream, and downstream. The water samples were then preserved with HNO3. After that, Nannochloropsis sp. cultures were conducted, and results showed an increase in algal population after 7 days. Subsequently, metal content testing was conducted using AAS (Atomic Absorption Spectrophotometer) with a wet-digestion technique to eliminate organic substances in the samples from each station. Metal content testing was conducted before and after treatment with algae. The results of this study showed a decrease in Pb metal levels at each station in the Jenes River after treatment with algae and 7 days of culture. The average decrease obtained was 14.0 before treatment and 5.0 after treatment. Nannochloropsis sp. is an important bioremediation agent for degrading Pb (lead) contamination in river water resulting from excessive industrial waste. These findings contribute to the development of waste treatment to preserve the river ecosystem.
Keywords: Environmental pollution; bioremediation; algae; Pb (lead); batik industry

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INTRODUCTION

Surakarta is one of the cultural cities well known for its Batik. The batik industry is the fastest-growing industrial sector in the city. Many areas in Surakarta have developed their trade sector in the batik industry. Although the batik industry is a significant cultural tradition, it faces criticism for its environmental impact. Polluted rivers, often used as dumping grounds for industrial waste by batik manufacturers, bear the brunt of this pollution. Effluents, particularly black chemical liquids, pose a significant threat to aquatic ecosystems.

One example of a river in Solo affected by waste is the Jenes River. Originating in Boyolali and flowing towards Laweyan, Pasar Kliwon, and ultimately Sukoharjo, the Jenes River is a tributary of the Bengawan Solo. Notably, the Jenes River stands out as one of the tributaries with the highest levels of Cadmium (Cd) and Chromium (Cr) contamination, exceeding the quality standard by a factor of 16. This concerning level of pollution, primarily attributed to recent discharges of chemical waste from the batik industry, has positioned the Jenes River as a separator between Sukoharjo Regency and the already concerning quality of other Bengawan Solo tributaries.

The Jenes River is currently classified as a tributary of Bengawan Solo, which is categorized as heavily polluted according to a study conducted by Surakarta Environmental Service. The primary source of contamination is the discharge of untreated effluents from multiple batik home industries. Local monitoring data indicate that concentrations of hazardous pollutants exceed established safety standards, rendering the water unsuitable for agricultural and fisheries use. Consequently, this pollution poses a significant threat to the local economy and the sustainability of the aquatic ecosystem.

Dyestuff waste produced by the batik industry is a non-biodegradable organic compound that can cause environmental pollution, especially in aquatic environments. In staining processes, this compound is only used in approximately 5% as a color enhancer, while the remaining 95% is disposed of as waste. This compound is quite stable, so it is very difficult for it to be degraded in nature and is harmful to the environment, which can harm the water content, especially in very large concentrations, as it can increase the *Chemical Oxygen Demand* (COD). COD is the amount of oxygen required for waste materials in water to be oxidized through biologically degradable chemical reactions.

Batik liquid waste has several characteristics, including concentrated color, viscosity, strong odor, turbidity, phenol, sulfide, BOD, COD, TSS, and high acidity (pH). In addition, heavy metal content is also present in batik liquid waste, which is difficult to decompose by microorganisms, including Pb, Cu, Cr, Cd, Zn metals, suspended solids, and other organic substances (Dwisandi et al., 2021). Phytoplankton (e.g. *Nannochloropsis sp.*) contain O, N, and S, which are double chains in proteins. Organic ligands can form strong bonds with Pb that is dissolved in aquatic environments. *Nannochloropsis sp.* can be used as a chelating agent for heavy metals dissolved in water.

Lead (Pb) is a heavy metal pollutant that has the potential to degrade and damage environmental quality and is usually found in industrial wastewater (Malik et al, 2021). Lead (Pb) is a class B metal ion with strong toxicity (Juharna et al., 2022). Lead is widely used in industries such as the chemical and printing industries and industries that produce metals, paints, and fumes from motor vehicles. Pb from factory effluents can contribute to the contamination of river water (Kamarati et al., 2018).

Some organic compounds inside phytoplankton, such as chlorophyll, can bind to heavy metals to form complex compounds through heavy metal-reactive groups, such as sulfhydryl and amine. Nannochloropsis *sp.* synthesizes metal-chelating proteins through active processes. Phytochelatins are synthesized from tripeptide derivatives (glutathione) consisting of glutamate, cysteine, and glycine. Glutathione is present in all cells (Grill et al., 1989).

This absorption ability of algae is due to the presence of carboxylate, sulfate, amine, and amide functional groups in the cell wall, which can bind metal ions. Ionic bonding occurs between the negative charge on the functional groups in the microalgae cell wall and the positive charge of Pb heavy metal ions (Melati, 2020). Carboxyl and amine groups play a greater role in the absorption of metal ions by *Nannochloropsis sp.* These groups contain free electron pairs that can interact with metal ions. Interactions can occur through several mechanisms, such as chelation, ion exchange, reduction, and complexation (Grill et al., 1989).

Bioremediation is the process of decomposing organic or inorganic pollutants from organic waste using organisms (bacteria, fungi, plants, or their enzymes) to control pollution under controlled conditions into a harmless material or its concentration is below the limit set by the authorized agency, with the aim of controlling or reducing pollutants from the environment (Anggraeni & Triajie, 2021). Bioremediation technology uses biological systems to remediate environmental pollution. Bioremediation can be performed by utilizing the potential of microalgae grown in a controlled media environment and then cultivated in media exposed to waste (Anggiani, 2020).

The effectiveness of bioremediation depends on the ability of microbial metabolism to degrade, detoxify, or transform pollutants, which is influenced by the accessibility and bioavailability of pollutants. The effectiveness of microorganisms is influenced by environmental conditions such as substrate (type and type of compound being degraded), temperature, and humidity (Meisyara, 2020). Bioremediation is a highly efficient, cost-effective, and environmentally friendly remediation technique (Amelia & Sulistiyaning, 2021). Bioremediation involves the use of biological agents such as bacteria, fungi, algae, and higher plants, both aquatic and terrestrial, to remove or reduce harmful pollutants and restore the ecosystem to its original condition (Aznur et al., 2022). Depending on the chemical nature of the contaminant, the bioremediation agent used must be chosen carefully as it only survives within the specified limits of the chemical contaminant. The remediation of pollutants using algae is known as phytoremediation (Aznur et al., 2022). This study aims to determine the effectiveness of Nannochloropsis sp. as a bioremediation agent for Pb in the Jenes River water in the batik industry area. This research is expected to contribute to the development of environmentally friendly waste treatment for the restoration of waters affected by batik industry waste.

METHOD

The Instruments used in this study included measuring flasks, watches, Erlenmeyer flasks, beakers, and stirrers using Iwaki Pyrex, a spuit using Onemed, a magnetic stirrer using DLAB, an Eastern Medical Autoclave, an analytical with Delibrated, a microscope from OptiLab, and a spectrophotometer from Parkin Elmer PinAAcle 900T. The materials utilized for this project consisted of algae directly sourced from the cultivation site, Blue Ocean salt, and Bioboost algae fertilizer. The research procedures consisted of a river water sampling process, followed by sample preparation, *Nannochloropsis sp.* cultivation, and initial Pb metal content test before treatment with *Nannochloropsis sp.* and after treatment with *Nannochloropsis sp.*, followed by an analysis process.

Sampling of the Jenes River was conducted during the day at three different stations: upstream, midstream, and downstream. It was taken during the day at with the consideration that factory activities to produce waste are high during the day. Samples of Jenes River water were collected and placed in a glass bottle, and then tested with HNO3. The concentrated HNO3 solution serves as a destructor because of its corrosive nature and low pH, which allows the sample to dissolve more easily for preparation (Hasmizal & Bhernama, 2021). The sample under study is a liquid sample, so the deconstruction carried out is wet deconstruction, by adding concentrated HNO3 so that the sample pH is less than 2 and then evaporation is conducted. The test materials were prepared using the wet-deconstruction method (wet calibration). The purpose of the wet deconstruction method in making the test solution is to remove organic substances contained in the sample (Nadia & Daulay, 2019).

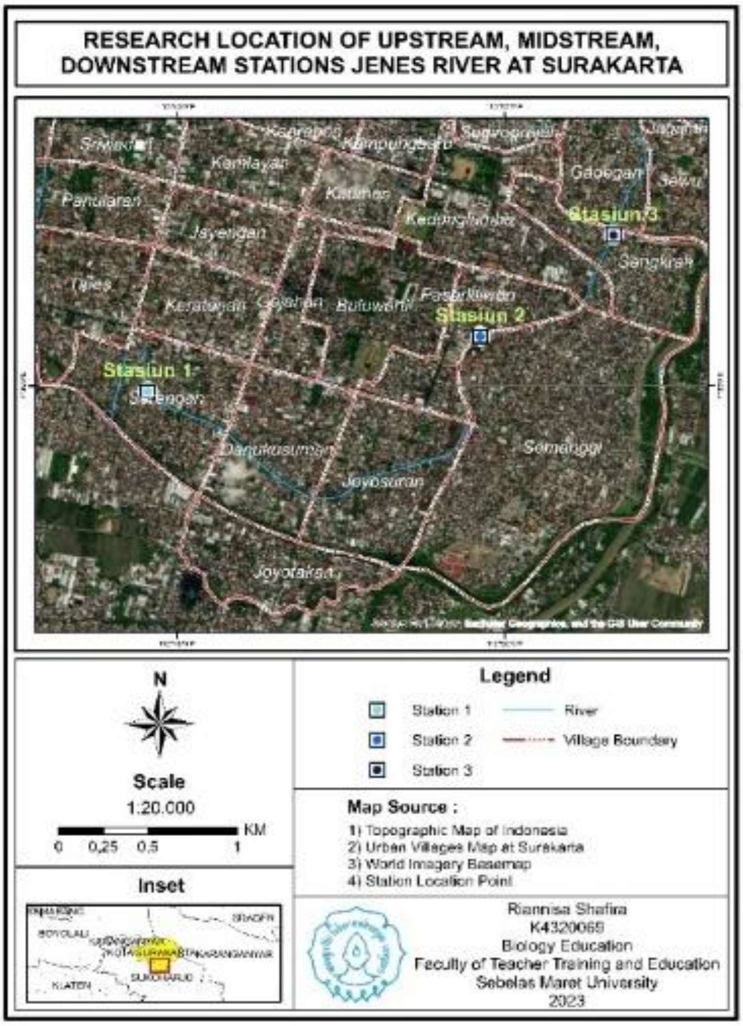

Figure 1. Sampling Map

Test Sample Preparation

All stages of research starting from sample preparation to metal content testing were carried out at the Integrated Laboratory of Sebelas March University. At the preparation stage of the test sample, first, 100 mL of river water sample was added into a glass cup, mixed until homogeneous, then 5 ml of nitric acid was added, heated over a Bunsen burner until the solution reached half of the initial volume, 5 ml of distilled water was added, poured into a 100 ml volumetric flask through filter paper, and 100 ml distilled water was added. Initially, river water samples from each station were placed in glass bottles. The Pb standard solution was then diluted to concentrations of 0.0, 0.5, 1.0, and 1.5 ppm.

Nannochloropsis Cultivation

A bottle containing 500 ml of water with 250 g of ASW salt was prepared in a 1000 ml bottle, then 250 ml of *Nannochloropsis sp.* seeds and 2 ml of f2 fertilizer were added. Cultivation was carried out under conditions of media water pH 11.0, light intensity 1560 lx, salinity 9 ppt, and temperature 37.8 °C. The bottle was then closed, and a tube was added for aeration. It was placed under sufficient light intensity, and the aeration tube was kept on for 7 × 24 h.

Metal Levels Assay

The metal content assay was conducted in two stages: before and after the treatment of *Nannochloropsis sp.*

a. Pre Treatment Stages

This stage was carried out by testing the metal levels (Pb) using Atomic Absorption Spectrophotometer (AAS) analysis of each sample of the Jenes River contaminated with waste, that is, at the upstream, middle, and downstream stations. Tests were carried out using Wet Deconstruction at a wavelength of 283.3 nm by preparing standard solutions with concentrations of 0.0, 0.5, 1.0, and 1.5 ppm. This stage begins with the preparation of a standard solution of lead metal 100 mg/L, by pipetting 100 ml of 1000 mg/L Pb metal master solution into a 100 ml volumetric flask and adding diluting solution to the tera mark. The stage of making a working solution of Pb lead metal, first pipetting a number of 10 mg/L Pb solution according to the concentration above, then adding diluent solution until the tera mark. The obtained sample was tested for pH using a pH meter. Standard solutions were introduced into the AAS flame to generate a linear calibration curve. Upon achieving a satisfactory correlation coefficient for the standard curve, the digested sample was analyzed. The AAS converted the metal atoms into atomic vapor, which absorbed energy from the cathode lamp radiation. Absorbance values were then automatically translated into Pb concentrations using the standard curve equation (Harahap, 2018).

b. Post Treatment Stages

Four bottles containing *Nannochloropsis sp.* were prepared, each with a volume of 250 ml, and 500 ml of Jenes River water was added from each station. Sample 1 was a control treatment in which no river water containing metals was used. Sample 2 contained *Nannochloropsis sp.* grown in Jenes River water from the upstream station. Sample 3 contained *Nannochloropsis sp.* grown in Jenes River water at the middle station. Sample 4 contained *Nannochloropsis sp.* grown in Jenes River water at the downstream station. This procedure was carried out under the same environmental conditions as when culturing, with no additional salt and only 2 ml of f2 fertilizer. This process lasted for 7 days with a light intensity of 1560 lux, media pH of the three stations 9.0 - 11.0 and salinity of the three stations in the range of 7.0 - 9.0 ppt.

Data analysis

Algal density was calculated using a modified counting chamber method that incorporated the specified variables.

Formula for Algal Density:

$$N = n \times \frac{A}{a} \times \frac{V}{VC} \times \frac{1}{V}$$

Description:
N : Phytoplankton Abundance (cell/ml)
n : Number of enumerated phytoplankton (cells)
a : Area of one field of view
V : Volume of concentrated water
A : Area of cover glass
VC : Volume of water under the cover glass
V : Filtered water volume

Cell density was measured daily for all samples over the 7-day period. The daily density increase of Nannochloropsis sp. is classified as 'Good' due to a significant positive linear trend observed over consecutive days, which demonstrates the species' tolerance to prevailing water conditions.

RESULT AND DISCUSSION

Nannochloropsis sp. is a phytoplankton that size of 2-4 μm, greenish in color, non-motile, and non-flagellated. The cells were spherical and small. *Nannochloropsis sp.* has a cell wall, mitochondria, chloroplasts and a membrane-covered nucleus. Chloroplasts are bell-shaped structures located at the edge of the cell and have stigmas (eye spots) that are sensitive to light (Ermavitalini et al., 2019). *Nannochloropsis sp.* can photosynthesize because they have chlorophyll a and c. A distinctive feature of *Nannochloropsis sp.* is its cell wall, which is composed of cellulose components (Zulfahmi et al., 2021). *Nannochloropsis sp.* has a protein content of 15%, carbohydrates, 0.59% calcium, and 0.57% phosphorus, which is composed of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Safitri et al., 2019). *Nannochloropsis sp.* algae belong to the kingdom Eukaryota, division Heterokontophyta, class Eustigmatophyceae, and genus Nannochloropsis (Zulfahmi et al., 2021).

Based on the *Nannochloropsis sp.* culture that has been conducted, phytoplankton growth is generally characterized by four stages: the adaptation, exponential, stationary, and death stages. The lag or adaptation phase is when cells adapt to their new environment. This phase usually occurs from day 1 to day 3. In the lag growth phase, microalgal cells placed in a bottle begin to adapt to the environmental conditions in the bottle (Zulfahmi et al., 2021).

Physiologically, cells prepare themselves for cell division at a mature age by producing enzymes and other metabolic compounds required for cell division. In this phase, the cells that divide are still small, so the number of cells does not increase significantly. Therefore, this phase is also called the lag phase. After that, the cells enter the exponential growth phase, where they divide rapidly, and the enzymes and metabolite compounds needed for cell division are readily available. The growth phase with rapidly increasing density occurs in the exponential phase, marked on day 4 to day 6 (Zulfahmi et al., 2021).

One of the marine microalgae, *Nannochloropsis sp.*, has a lipid content of 12.0-53.0% per gram dry weight of biomass, but under stress conditions, the lipid content of *Nannochloropsis sp.* can reach 90% per gram dry weight (Ermavitalini et al., 2019). Green algae can adsorb metal ions in living or dead conditions because their functional groups can act as ligands, namely, -COOH and -NH2 groups that can bind to metal ions (Meisyara, 2020). This stage was conducted at the Biology Education Laboratory of Sebelas March University.

Nannochloropsis sp. cultivation was performed for 7 days, considering the optimum time for *Nannochloropsis sp.* to reproduce. In the culturing process, it is very important to adjust the environmental conditions including light intensity, salinity, aeration, and temperature to ensure that Nannochloropsis can survive and reproduce optimally. The culture is based on environmental conditions in accordance with its natural habitat in seawater, with a salinity of 9 ppt. *Nannochloropsis sp.* lives abundantly in marine or freshwater, growing at a salinity of 0-35 ppt, with an optimum salinity of 25-35 ppt (Firgiandini, 2019). *Nannochloropsis sp.* cell growth is strongly influenced by three important components: light, carbon dioxide and nutrients. *Nannochloropsis sp.* is one of the most efficient plants in capturing and utilizing light energy and CO2 for photosynthesis (Hadiyanto & Adetya, 2018).

Tabel 1. Algae culture growth

Inokulan	Algae growth per day	Result (cell/ml)
16.410.000 cell/ml	Day 1	2.145.000
	Day 2	5.589.000
	Day 3	8.928.000
	Day 4	11.568.000
	Day 5	13.284.000
	Day 6	17.580.000
	Day 7	17.580.000

Description: Algal growth increases day 1 until day 7. The algae reached the stationary phase on day 6, during which the rate of cell growth equals the rate of cell death due to limited growth space or nutrient depletion in the medium.

Cultured *Nannochloropsis sp.*

For 7 days, algae density was observed using SRC with dimensions of 50 mm x 20 mm x 1 mm sampled with 1 mL with a volume of 1 mL with a 10 × 10 magnification microscope. Algal growth was observed using a Nikon Eclipse E100 microscope at magnifications of 10x (Figure 1), 40x (Figure 2) and 100x (Figure 3), then observed under a microscope and counted the number of algae density using a hand counter. Plankton was observed first. Then, 0.05 ml of filtered water was dripped into the SRC and closed neatly using a prep glass until there were no water bubbles. The plankton on the Sadgewich Rafter under a microscope were then activated and counted according to the order of the boxes in the Sadgewich Rafter (Prahitaningrum, 2023).

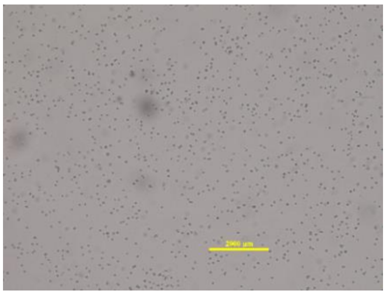

Figure 2. 10x Magnification

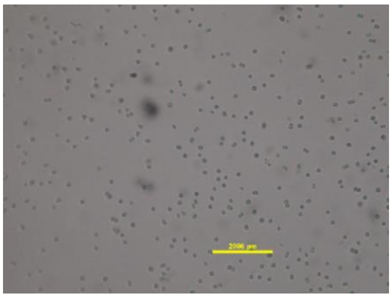

Figure 3. 40x Magnification

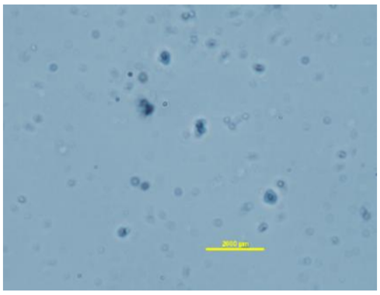

Figure 4. 100x Magnification

Characteristics of Pb (Lead) Metal

Heavy metal contamination of aquatic environments arises from various sources. These can be broadly categorized into two main pathways: natural processes, such as volcanic eruptions, and anthropogenic activities, exemplified by the improper disposal of industrial solid and liquid waste. Heavy metals are considered one of the most toxic water pollutants because they are difficult to degrade and accumulate at the bottom of water bodies and in the bodies of organisms through the food chain (Aznur et al., 2022).

Lead is a bluish-grey metal element of group IVA with a high density, an atomic mass of 207.2 amu, atomic number 82, a melting point of 600.65 °K, and a boiling point of 2023 °K. It is soluble in concentrated HNO3 and slightly soluble in HCI and dilute H2SO4 at room temperature. The solubility of lead is quite low; therefore, the level of lead in water is relatively low (Fadhila & Purwanti, 2022). The properties of lead based on its physical and chemical properties include: 1) a low melting point; 2) it is a soft metal that is easily transformed into various shapes; 3) lead can form alloys with other metals, and the alloys formed have different properties from pure lead; 4) it has a high density compared to other metals, except gold and mercury, which is 11.34 g/cm^3; and

5) the chemical properties of lead cause this metal to function as a protector when in contact with humid air.

The presence of heavy metal lead (Pb) in water from industrial wastewater is significantly harmful to marine organisms and indirectly threatens human health through food chain contamination. Lead (Pb) is a highly toxic heavy metal that is not expected to exist in the body of living organisms, even in very small amounts. Lead can enter the human body through the respiratory tract (inhalation), digestive tract (oral), and skin (dermal), such as when humans breathe (inhale), eat, swallow, absorb through the skin, or through the placenta of pregnant women who suffer from lead poisoning and drink any substance containing lead (Ahmad et al, 2021). These heavy metals, which are naturally difficult to decompose, can easily accumulate in aquatic environments. Heavy metals are generally toxic to living organisms (Anggraeni & Triajie, 2021).

Based on the description given above, a test was then carried out to determine the metal content before handling the samples of the three stations from Jenes River using an Atomic Absorption Spectrophotometer and the results obtained as follows.

Table 2. Concentration of Heavy Metal Lead (Pb)

Heavy Metal Type	Metal Concentration (mg/L)	Grade II Quality Standard
Pb (Lead)	**Upstream**	**0,03**
	Sample 1: 1,656	
	Sample 2: 0,766	
	Sample 3: 0,482	
	Midstream	**0,03**
	Sample 1: 1,668	
	Sample 2: 0,745	
	Sample 3: 0,531	
	Downstream	**0,03**
	Sample 1: 1,662	
	Sample 2: 0,801	
	Sample 3: 0,582	

Description: Concentration of Heavy Metal Lead (Pb) in Jenes River Solo After Treatment of *Nannocloropsis sp.*

Based on the table above, it can be stated that the metal content (Pb) in Jenes River water at each station, that is, upstream, middle, and downstream, is classified as high based on the Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management-Quality Standards for River Water and its Kind. In all samples from upstream, middle and downstream with 3 repetitions, the results showed that all stations have metal content contained > 0.03. Thus, the Pb metal content in the Jenes River exceeds the quality standard set by the Ministry of Environment and Forestry.

After conducting metal content tests before *Nannochloropsis sp.* treatment, metal levels were tested after treatment with Nannochloropsis sp. and the following results were obtained.

Table 3. Concentration of heavy metal lead (Pb)

Heavy Metal Type	Metal Concentration (mg/L)	Grade II Quality Standard
Pb (Lead)	**Upstream**	**0,03**
	Sample 1: 0,013	
	Sample 2: 0,009	
	Sample 3: 0,009	

Heavy Metal Type	Metal Concentration (mg/L)	Grade II Quality Standard
	Midstream	**0,03**
	Sample 1: 0,023	
	Sample 2: 0,025	
	Sample 3: 0,022	
	Downstream	0,03
	Sample 1: 0,035	
	Sample 2: 0,024	
	Sample 3: 0,015	

Description: Concentration of Heavy Metal Lead (Pb) in Jenes River Solo After Treatment of *Nannocloropsis sp.*

Based on the table above, in the three samples from each station, upstream, downstream, and middle with three repetitions, the results showed that after treatment, there was a decrease in metal levels. Quantitative data regarding Lead (Pb) concentrations were analyzed to determine the effectiveness of the bioremediation process. Bioremediation using Nannochloropsis sp. has been demonstrated to significantly reduce lead (Pb) concentrations, thereby improving water quality in the Jenes River from heavily polluted conditions to compliance with quality standards. Data analysis indicated a substantial decrease in Pb concentration from an initial range of 0.482–1.668 mg/L to a safe range of 0.009–0.035 mg/L after seven days of incubation, achieving an absorption efficiency exceeding 97%. This reduction is attributed to an active biosorption mechanism, in which increased algal biomass provides more active sites in the form of negative functional groups on the cell wall. These sites strongly bind Pb^{2+} ions through ionic exchange and complex formation, effectively trapping the heavy metal within the biomass and removing it from the aquatic environment (Ermavitalini et al., 2019).

The statistical significance of the reduction in heavy metal content was evaluated using the Mann-Whitney U Test. This nonparametric test was selected because the Shapiro-Wilk indicated that the environmental data did not follow a normal distribution, and because the study involved a limited sample size, which precluded the use of parametric t-tests (Nachar, 2008). The analysis was performed using SPSS 26.0 with a confidence level of alpha = 0.05.

Table 4. Mann Whitney Test

	Treatment	N	Mean Rank	Sum of Rank	Asymp.Sig
Heavy Metal Concentration	Pretreatment	9,0	14,0	126,0	0,00
	Posttreatment	9,0	5,0	46,0	0,00
	Total	18,0			

Description: Mann–Whitney test was conducted to determine the significant difference between before and after treatment with *Nannochloropsis sp.*

Based on the table results, it can be seen that the Asymp-Sig (2-tailed) value is 0.00 <0.05. Therefore, it can be concluded that the hypothesis is accepted". This indicates a difference in the average metal levels before and after treatment with *Nannochloropsis sp. Nannochloropsis sp*. is considered capable of bioremediation to degrade Pb (lead) metal content polluted in Jenes River water caused by excessive factory waste activities.

The success of this metal reduction is also supported by *Nannochloropsis sp.*'s adaptive ability. A study by Meisyara (2020) explains that certain microalgae species, due to their functional groups, can act as ligands, namely the -COOH and -NH2 groups, which can bind metal ions. This mechanism allows the algae to bind and detoxify metals that enter the cytoplasm, preventing cellular damage, enabling them to continue growing healthily (Table 1), and allowing them to continuously accumulate pollutants from the aquatic environment. Thus, Pb reduction in this study is due to cell wall adsorption and the algae's physiological defense mechanisms.

The aim of this study aligns with the positive results between the adaptive ability of *Nannochloropsis sp.* and the efficiency of metal absorption. Cell growth data reaching the stationary phase at a density of 17,580,000 cells/ml indicate that this species has high resistance to the toxins present in batik wastewater. During a 7-day treatment, *Nannochloropsis sp.* was shown to reduce Pb levels from extreme concentrations to below quality standards. Thus, these findings address the research objective that *Nannochloropsis sp.* is effective in accumulating pollutants and has potential as a bioremediation agent in polluted aquatic ecosystems.

CONCLUSION

This study shows that Nannochloropsis sp. is highly effective in handling Lead (Pb) contamination in the Jenes River by successfully reducing the concentration to safe regulatory standards (Class II) within 7 days. Unlike previous research limited to synthetic media, these findings confirm the microalgae's ability to break down heavy metals in complex and real batik wastewater. Therefore, Nannochloropsis sp. offers an environmentally friendly alternative to be integrated into Wastewater Treatment Plants (IPAL) to reduce industrial pollution in river ecosystems.

RECOMMENDATION

Further research is recommended to test the effectiveness of Nannochloropsis sp. under various environmental conditions and exposure durations, as well as to compare it with other microalgae in order to obtain the most optimal and applicable Pb bioremediation agent in the field.

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