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Original Paper

Development of a treatment system utilizing *Spirogyra* sp. extract for the purpose of treating industrial wastewater

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ABSTRACT

The study included the design of a treatment unit using *Spirogyra* sp. algae for industrial wastewater from the developed industrial area in Kirkuk City, Iraq. The use of algae in the bioremediation of industrial wastewater is considered one of the best treatment technologies because it is safe, inexpensive, and based on materials naturally available in the environment. The results showed that the algal filter containing *Spirogyra* sp. improved the wastewater quality, bringing the treated water within the permissible Iraqi standards for irrigation. Regarding heavy metals, the highest removal efficiency was recorded for cadmium (Cd), at 98.7%, followed by lead (Pb), at 98.6%, whereas the lowest removal efficiency was recorded for iron (Fe), at 85.33%, indicating a clear decrease in heavy metal concentrations. The sodium adsorption ratio decreased from 2.69 mEq/L before treatment to 1.99 mEq/L after treatment. Sodium percentage (Na%) decreased from 20% before treatment, when the water was classified as good for irrigation, to 17% after treatment, when the water was classified as excellent for irrigation. The magnesium adsorption ratio of the industrial wastewater was 52.88 mEq/L before treatment, indicating that the water was unsuitable for irrigation. After treatment, it decreased to 47.50 mEq/L, allowing the water to be classified as suitable for irrigation. The Kelly ratio decreased from 0.27 mEq/L before treatment to 0.22 mEq/L after treatment. Potential salinity decreased from 21.57 mEq/L before treatment to 7.17 mEq/L after treatment. Overall, the *Spirogyra* sp. algal filter showed high efficiency in treating industrial wastewater and improving its properties for potential reuse in irrigation.

Keywords: *Bioremediation, Heavy Metals, Industrial wastewater, Spirogyra sp.*

1 INTRODUCTION

Algae inhabit diverse aquatic environments, including freshwater, brackish water, and marine environments with high salinity levels [1]. They show varying preferences for temperature, pH, and nutrient availability and play a fundamental role as primary producers at the base of the food chain. According to [2], algae vary in their habitat preferences based on their photosynthetic activity. Some algae thrive in flowing water, whereas others prefer still water found in lakes. In addition, some algae thrive in saline water, whereas others prefer freshwater environments. Certain algal species can also serve as indicators of pollution.

Therefore, to identify and locate specific algal species, it is necessary to understand the environmental conditions preferred by each species, including temperature, water characteristics, and other physicochemical parameters [3]. Photosynthesis is a process by which algae convert light energy into chemical energy within the cell [4]. Seaweeds, also known as macroalgae, are found in seawater. The term "phytoplankton" is used to describe unicellular microalgae because of their small size, which is invisible to the unaided eye [5].

The use of algae in wastewater treatment eliminates or reduces the need for harmful chemical substances, thereby preventing the formation of additional toxic compounds that may be more hazardous than the original contaminants [6]. In addition, algal treatment produces biomass that can be utilized for other purposes, as demonstrated in previous research [7].

Industrial wastewater resulting from different industrial activities contains heavy metals that can reach water bodies and harm aquatic life, animals, humans, and plants, either directly or indirectly, thereby negatively affecting the ecosystem [8]. Heavy metals are difficult to remove from soil and water because they are widely distributed and increasing because of industrialization, which is necessary for the development of any country.

Using algae in the bioremediation of industrial wastewater is considered one of the best treatment technologies because it is safe, inexpensive, eco-friendly, based on naturally available materials, and supported by the ability of algae to adapt to extreme conditions. *Spirogyra* sp. is a filamentous alga characterized by helically arranged chloroplasts [9]. The aim of this study was to evaluate the efficiency of *Spirogyra* sp. in treating industrial wastewater for potential reuse in irrigation.

2 MATERIALS AND METHODS

Industrial wastewater samples were collected from the developed industrial area in Kirkuk City, Iraq, in sterile plastic containers. Three samples, each with a volume of 15 L, were collected. Algal specimens were also collected from the Khasah Su Canal located in Kirkuk City. The Khasah Su Canal runs through Kirkuk City from its center, dividing it into eastern and western sides. The total length of the Khasah Su Canal is approximately 190 km, of which 16 km passes through the center of Kirkuk City [10].

Fig. 1 *Spirogyra* sp. sample collection sites Khasah Su canal in Kirkuk City.

The algae were collected from the edges of the Khasah Su Canal, washed several times with distilled water, and stored in plastic containers for transport to the laboratory. Subsequently, the algae were identified as described by [11]. *Spirogyra* is a filamentous alga with no clear physiological specialization among its cells. Its thallus consists of long, unbranched filaments arranged as a single row of cells that are similar in shape, structure, and function. The algae were identified by direct examination using a compound light microscope (OMAX) at 40× and 100× magnification.

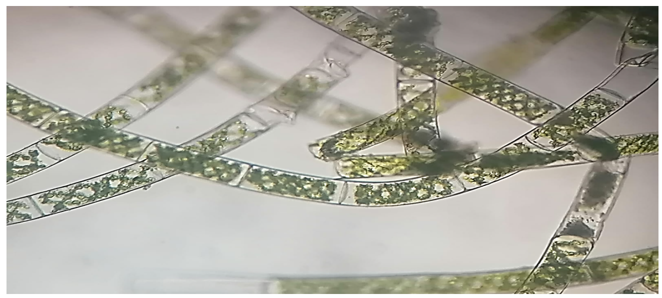

Fig. 2 *Spirogyra* sp. observed under a light microscope.

After isolation, the algal samples were dried at laboratory temperature and then ground into powder using a ceramic grinder. A jar test was performed to select the optimal algal powder concentration, using 10 g of algal powder for 1000 mL of industrial wastewater, and to determine the time required for treatment.

The treatment process involved constructing a polyethylene filter with a diameter of 8 cm and two openings. One opening allowed the entry of untreated industrial wastewater, while the other allowed the discharge of treated water. The pre-prepared algal material containing the powder was then introduced into the filter. The estimated algal powder weight was 10 g, and the physicochemical properties and concentrations of pollutants in the industrial wastewater were determined before and after treatment. The treatment duration was 24 h at laboratory temperature, and the experiment was repeated three times (Figure 3). The removal percentage was calculated according to the method described in [12]. The physicochemical properties of industrial wastewater, including EC, alkalinity, total hardness, TDS, TSS, Ca, Mg, Na, K, PO_4, NO_3, SO_4, and Cl, were measured before and after treatment according to the method described by [13].

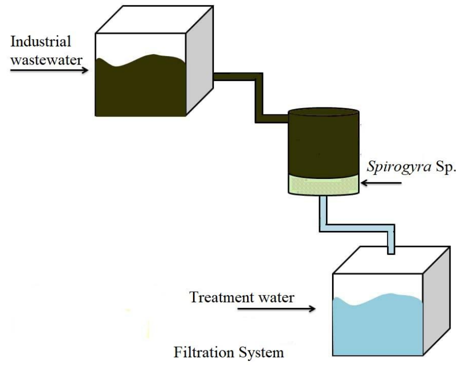

Fig. 3 Filtration system for treatment of industrial wastewater.

An atomic absorption spectrophotometer was used to measure heavy metal concentrations in industrial wastewater before and after treatment [14]. Irrigation parameters were calculated using the following equations:

$$\text{Sodium adsorption ratio (SAR)} = \text{Na}^+ / \sqrt{\left[\left(\text{Ca}^{2+} + \text{Mg}^{2+}\right)/2\right]} \quad (1)$$

$$\text{Sodium percentage (Na\%)} = 100 \times \left(\text{Na}^+ + \text{K}^+\right) / \left(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+\right) \quad (2)$$

$$\text{Magnesium adsorption ratio (MAR\%)} = \text{Mg}^{2+} \times 100 / \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right) \quad (3)$$

$$\text{Kelly ratio (KR)} = \text{Na}^+ / \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right) \quad (4)$$

$$\text{Potential salinity (PS)} = \text{Cl}^- + 0.5 \times \text{SO}_4{}^{2-} \quad (5)$$

3 RESULTS AND DISCUSSION

The results of the study showed that the concentrations of most examined parameters decreased after treatment, resulting in increased removal percentages for all parameters, as shown in Table 1. Treatment with *Spirogyra* sp. improved the properties of industrial wastewater, supporting its potential reuse for irrigation.

As shown in Table 1, the pH of industrial wastewater changed from 6.8 before treatment to 7.2 after treatment with *Spirogyra* sp. This value is close to neutral and falls within the permissible Iraqi standards for irrigation water [15].

The values of EC, alkalinity, total hardness, TDS, TSS, Ca, Mg, Na, K, PO_4, NO_3, SO_4, and Cl decreased after treatment, with removal percentages of 97.5%, 71.81%, 55.53%, 87.71%, 66.66%, 54.54%, 63.33%, 68.00%, 57.89%, 72.70%, 49.83%, 64.70%, and 72.50%, respectively.

The highest removal percentage was recorded for EC, at 97.5%, whereas the lowest removal percentage was recorded for NO_3, at 49.83%. Although Mg showed a removal percentage of 63.33%, its concentration remained outside the permissible Iraqi standards for irrigation water after treatment with *Spirogyra* sp., as shown in Figure 4. These findings demonstrate the effectiveness of *Spirogyra* sp. in improving the quality of industrial wastewater.

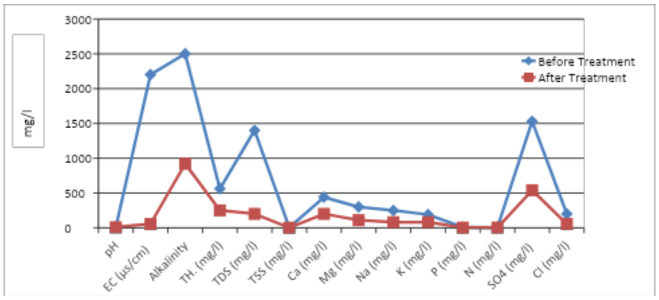

Fig. 4 Removal percentage efficiency of the *Spirogyra* sp. filter for treat some physical and chemical properties of industrial wastewater.

The study showed the high ability of *Spirogyra* sp. to remove heavy metals, as shown in Table 2. The highest removal percentage was recorded for cadmium (Cd), at 98.7%, followed by lead (Pb), at 98.6%, whereas the lowest removal percentage was recorded for iron (Fe), at 85.33%, as shown in Figure 5. These results illustrate the decrease in heavy metal concentrations after treatment.

In addition, Pb and Cd concentrations were outside the permissible Iraqi standards for irrigation water before treatment with *Spirogyra* sp.; however, after treatment, they decreased to within the permissible standards. The algal filter showed substantial improvement in most of the examined parameters after treatment.

Algae have the ability to grow and tolerate harmful environmental conditions in wastewater, making them versatile organisms for the treatment of different types of liquid waste generated by industrial, agricultural, and

Table 1 Removal efficiency of the *Spirogyra* sp. filter in treating selected physical and chemical properties of industrial wastewater

Parameters	Car-wash wastewater before treatment	Car-wash discharge water after algae treatment	Standards [12]	Removal percentage (%)
pH	6.8^{a}	7.2^{a}	4–8.6	–
EC (μS/cm)	2200^{a}	55^{b}	–	97.50
Alkalinity (mg/L)	2500^{a}	920^{b}	–	71.81
Total hardness (mg/L)	560^{a}	250^{b}	–	55.53
TDS (mg/L)	1400^{a}	200^{b}	2500	87.71
TSS (mg/L)	3.3^{a}	1.1^{b}	40	66.66
Ca (mg/L)	440^{a}	200^{b}	450	54.54
Mg (mg/L)	300^{a}	110^{b}	80	63.33
Na (mg/L)	250^{a}	80^{b}	250	68.00
K (mg/L)	190^{a}	80^{b}	100	57.89
PO_4 (mg/L)	8.5^{a}	2.32^{b}	25	72.70
NO_3 (mg/L)	6.22^{a}	3.12^{b}	50	49.83
SO_4 (mg/L)	1530^{a}	540^{b}	–	64.70
Cl (mg/L)	200^{a}	55^{b}	–	72.50

Note. Values followed by different superscript letters indicate significant differences between the studied treatments at $P \leq 0.05$, whereas values followed by the same letter indicate no significant difference.

Abbreviations: EC, electrical conductivity; TDS, total dissolved solids; TSS, total suspended solids.

other activities [16]. In addition, algae are capable of removing heavy metals from contaminated water [17].

Table 2 Testing the removal percentage efficiency of the *Spirogyra* sp. filter for treat heavy metals.

Parameters	Car Washes Treat Wastewater Before To Disposal	Car Washes Discharge Water Including Algae As Waste	Standards [12]	Removal Percentage (%)
Fe (mg/l)	3.75a	0.55b	5	85.33
Pb (mg/l)	2.19a	0.03b	0,1	98.63
Cd (mg/l)	1.55a	0.02b	0,01	98.70

Note. Concentrations with different letters mean that there are significant differences between them relative to the studied factors at a significance level of $P \leq 0.05$, while similar letters mean that there are no significant differences.

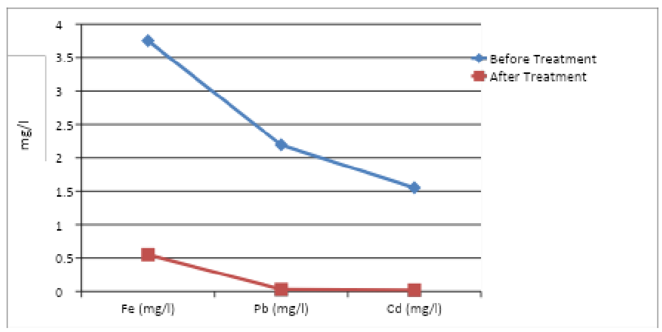

Fig. 5 *Spirogyra* sp. filter efficiency for treating heavy metals of industrial wastewater.

Some irrigation suitability indices for industrial wastewater were calculated before and after treatment with *Spirogyra* sp. (Table 3). The results showed that the sodium adsorption ratio (SAR) decreased from 2.69 before treatment to 1.99 after treatment, remaining within the permissible limits for irrigation water [18]. This decrease may be attributed to the higher concentration of calcium ions compared with sodium ions. SAR represents the relationship between sodium ions and calcium plus magnesium ions and is an important indicator of the harmful effects of sodium on soil structure and permeability [19].

The results showed that sodium percentage (Na%) was 20% before treatment, and the water was classified as good for irrigation. After treatment, Na% decreased to 17%, and the water was classified as excellent for irrigation [20]. Sodium percentage is an important indicator of sodium hazard relative to the total concentration of major cations. High sodium percentages can negatively affect soil permeability and plant growth [21].

As shown in Table 3, the magnesium adsorption ratio (MAR) of industrial wastewater was 52.88% before treatment, indicating that the water was unsuitable for irrigation. After treatment, MAR decreased to 47.50%, allowing the water to be classified as suitable for irrigation [22]. This indicates the ability of *Spirogyra* sp. to improve the quality of industrial wastewater. Magnesium ions are important for plants because moderate concentrations contribute to root and vegetative growth, fruit development, cell division, and photosynthesis. However, excessive magnesium concentrations may have negative effects on plants [23].

The results showed that the Kelly ratio (KR) of industrial wastewater decreased from 0.27 before treatment to 0.22 after treatment. KR is an important parameter for evaluating irrigation water quality and is calculated based on the ratio of sodium ions to the sum of calcium and magnesium ions in irrigation water. The decrease in KR may be attributed to higher concentrations of magnesium and calcium compared with sodium. According to approved international classifications, this water can be considered suitable for irrigation [24].

The results in Table 3 also showed that potential salinity (PS) decreased from 21.57 before treatment to 7.17 after treatment. This indicates the high ability of *Spirogyra* sp. to reduce PS values. Therefore, the treated water can be considered suitable for irrigation according to approved international classifications [25]. PS reflects the effect of sulfate and chloride ions in irrigation water and is one of the important criteria for determining water quality and irrigation suitability. High sulfate and chloride concentrations can contribute to soil salinization and leaf burn, negatively affecting plant production quality and quantity [26].

Table 3 Irrigation standard values for industrial wastewater before and after treatment with *Spirogyra* sp.

Tests and References	Before Treatment	After Treatment	Standards
SAR (mEq/L) [14]	2.69	1.99	0–10 Good
			10–18 Suitable
			18–26 Doubtful
			26 < Bad
Na (%) [16]	20	17	20 > Excellent
			20–40 Good
			40–60 Allowed
			60–80 Doubtful
			80 < Not suitable
MAR (%) [18]	52.88	47.50	50 > Suitable
			50 < Not suitable
KR [24]	0.27	0.22	1.0 > Suitable
			1.0 Not suitable <
PS (mEq/L) [21]	21.57	7.17	25 > Good
			25–75 Suitable
			75 < Weak

4 CONCLUSION

Industrial wastewater showed values higher than the permissible limits according to Iraqi standards. The algal filter containing *Spirogyra* sp. demonstrated high efficiency in removing pollutants from industrial wastewater, especially heavy metals. The results of this study showed that industrial wastewater treated with *Spirogyra* sp. can be reused for irrigation according to Iraqi standards.

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Data availability

N/A

DECLARATIONS

Conflict of interest

The authors declare no competing interests

Consent to publish

N/A

Ethical approval

N/A

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