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Effect of Mass Ratio on Phytoremediation of Nickel Contaminated Water

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Abstract

Water pollution is one of the global challenges that the society must address in the 21st century aiming to improve the water quality, reduce human pollutants and ecosystem health impacts. In phytotoxicity test, the plant of *Iresine herbstii* was exposed to remove nickel from simulated wastewater using two different ratios (mass of plant to the mass of nickel) (,$R_{p/Ni}$) for 21 days with sub-surface batch system. During the exposure period, the removal of Ni concentrations (2, 5 and 10 mg/L) for two mass ratio (2,800 and 34,000) were (83.6%, 77.2%, 78.0%) and (86.8%, 97% and 95.6%), respectively. final result of the rate was found that the highest removal occurred, 97%, at a mass ratio of 34,000 and a nickel concentration of 5 mg/L. Metal accumulation mechanism of plants were examined using bioconcentration factor (BCF) and translocation factor (TF) of metals which indicated that *I. herbstii* is suitable for phytostabilization of Ni (BCF>1 and TF<1). Therefore, the ability of *I. herbstii* to treat wastewater contaminated with nickel that *I. herbstii* is considered a potential plant to remove Ni from contaminated water.

Keywords**:** *Iresine herbstii, nickel removal, mass ratio, ornamental plant, phytoremediation.*

1. Introduction

Recently, solid and water wastes treatment are taking huge attention due to the higher generation of this wastes by industrialization and urbanization every year, which creates a big environmental problems worldwide [1]. Excessive or improper use of synthetic chemical compounds due to anthropogenic activities which have highly Affected on the environment and threatened human health (toxicity and carcinogenicity) [2]. Heavy metals, organic solvents, and hydrocarbons are among the major threat to land, air, and water [3]. Heavy metal bearing waters are considered a major environmental burden. They are posing risk to the ecological systems and human health even at low concentrations, since heavy metals are accumulative and non-biodegradable [4]. Heavy metals usually enter the environment either naturally through weathering of parent materials, or man-made through metals extraction from ores followed by subsequent processing for further use in numerous applications, and the discharge of high concentration metal waste by industries [5].

Nickel is a global trace element and the commonest metal that cause metal allergy among the people. Nickel allergy is a chronic, recurring problem; females are affected more commonly than males [6]. Water contaminated with nickel is from industries such as printing, electroplating, battery manufacturing industries, nickel refineries, and electronic products [7].

Constructed wetlands (CWs) can be an acceptable environmental option in domestic wastewater treatment. But this technology and its implementation in decentralization practices is still under discussion [8]. CWs have been commonly used in water treatment systems as substitute for conventional methods because of their low energy requirements as well as easy operation and maintenance [9]. Man-made systems have been design to drop the principle of natural wetlands for treating wastewater [1]. They are used widely as an inexpensive and easy to implement for treating wastewater from different sources [10].

It has been proven that plants have the ability to extract heavy metals from contaminated area [11,12]. The present study was carried out to examine which of the two different mass ratio ($R_{p/Ni}$) is the best ratio to remove nickel (Ni) from the sub-surface batch system. Consequently, the outcomes of this research are useful for selecting the appropriate mass ratio to reach efficient management site of phytoremediation via CW for any known wastewater pollutant concentration thus calculate the amount of plant required. As well as the objectives of the study is to investigate the ability of *Iresine herbstii* to grow and survive in wastewater contaminated with nickel, in order to identify the best removal based on plant to metal mass ratio and finally to determine the mechanisms involved in the removal of heavy metals.

2. Materials and Methods

2.1 Experimental Set-Up

The study was done in an open environmental area at Al-Khwarizmi College of Engineering, University of Baghdad. this study, nine aquariums made of glasses, each one with dimensions of 30×30×30 cm (Length ×Width ×Depth) with sub-surface batch system (SSB), were used as shown in Figure 1. In sub-surface batch (SSB) system, each aquarium was filled with large coarse gravel (Φ = 5-3 cm) with 10 cm depth followed by 10 cm fine gravel (Φ 1–2 cm). The water level was maintained within the fine gravel layer in order to simulate a sub-surface system as used in real wetlands. For this system, three aquariums for each minimum and maximum mass ratio ($R_{P/Ni}$) were used. Two mass ratio ($R_{P/Ni}$) factors of 2,800 and 34,000 were selected as the minimum and maximum values, respectively, according to Beaker's preliminary test optimization. The other three aquariums acted as control contaminant without plants.
Contaminated water of 5 L for each aquarium was prepared by mixing water with nickel to form different concentrations (2, 5, and 10 mg/L). The water level was kept within the gravel layer surface (up to 21 cm height of the aquarium) to simulate sub-surface batch system.

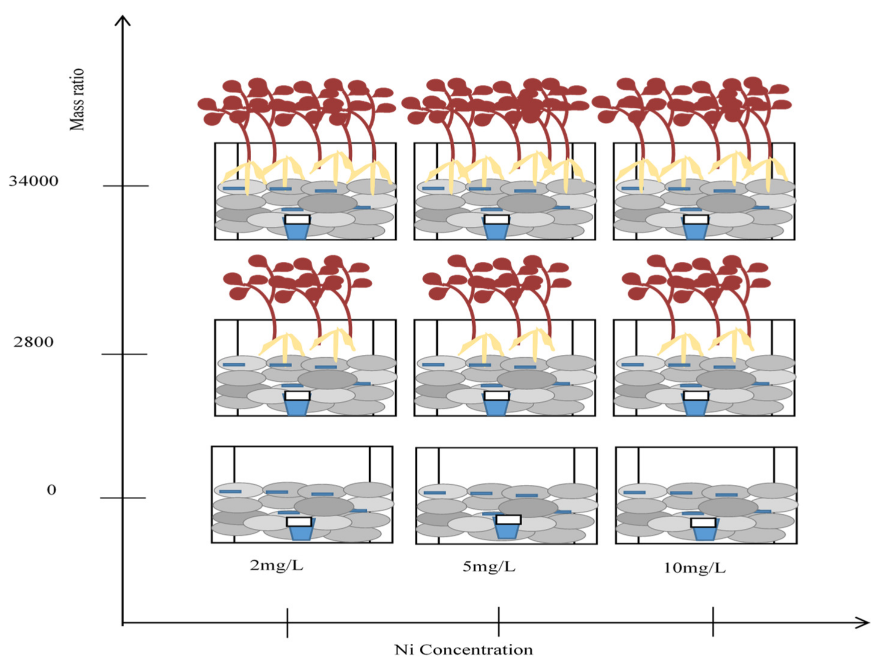

Fig. 1. Plants arrangement in the aquarium according to the mass ratio.

Table 1 shows the details of plant mass added to each aquarium for two mass ratios of 2,800 and 34,000 which were calculated according to the Equation (1):

$$\text{Mass Ratio}\left(R_{P/Ni}\right)=\frac{M_P}{M_{Ni}} = \frac{\text{Mass of Plant(g)}}{Ni_{ww}(g/L)\times V_{ww}(L)} \quad \ldots (1)$$

Where,
M_P is the mass of plant in (g),
M_{Ni} is the mass of nickel in (g/L),
Ni_{ww} is the concentration of nickel in wastewater in (g/L)
V_{ww} is the volume of wastewater in (L),

Table 1,
Plant mass planted in each aquarium with respect to Ni concentration

Mass Ratio	Minimum = 2,800			Maximum = 34,000		
	Ni concentration (mg/L)					
Plant mass (g)	2	5	10	2	5	10
	28	70	140	340	850	1,700

2.2 Physical Parameters Monitoring

During 21 days of experimental work, samples were taken from taps in each aquarium (Figure 2) at days 0, 7, 16, and 21. The physic-chemical changes in a water samples from each aquarium were recorded. The parameters of temperature T (°C), pH, and total dissolved solid (TDS, mg/L) were measured by ISO lab (3110- Germany) probe. Dissolved oxygen (DO, mg/L) was recorded by HACH (HQ430d, USA) probe.

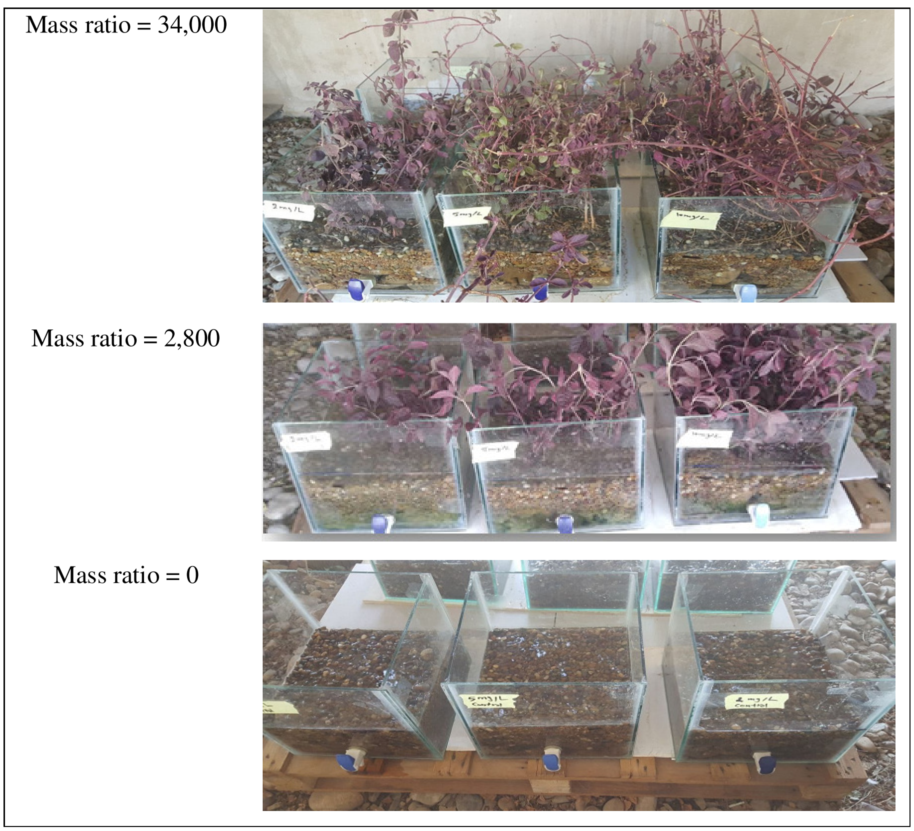

Fig. 2. Sub-surface batch system (SSB)

2.3 Analysis of Ni in Effluent

Water sample of 20 mL was collected from each aquarium on each sampling day (0, 7, 16, and 21) and stored it in clean tubes. The Ni analysis was done in the medium of water by using A atomic A absorption device (Model AA-7000, Shimadzu, Japan) at Iraq Ministry of Science and Technology. The Ni removal efficiency from water sample was determined by using equation (2):

$$\text{Nickel Removal}(\%) = \left(\frac{C_{Ni_0} - C_{Ni_t}}{C_{Ni_0}}\right) \times 100 \qquad \ldots(2)$$

Where

C_{Ni0} is the Ni concentration at time 0 (mg/L),

C_{Nit} is the Ni concentration at sampling time (mg/L).

2.4 Ni extraction in plant and Bio-concentration factor

The extraction process was carried out on aquariums with a mass ratio of 2,800 because the plant remained semi-healthy. One plant *I. herbstii* was harvested from each aquarium with different concentrations (2, 5, and 10 mg/L) of Ni. Plant was first washed with tap water, and then stem and roots parts were separated to dry in oven with temperature at 70℃. An amount of 5 g was accurately weighed for each of the stem and roots. The plant samples were mineralized to determine Ni content according to Turek et al., (2019) method [13]. Finally, Ni extraction from *I. herbstii* stem and roots were determined by Atomic Absorption device as explained in section 2.3.

Bio-concentration factor (BCF) of plants is the most important botanical feature in the phytoremediation process. It gives an idea about the uptake potential for the metals, their mobilization into plant tissues, and storage in the aerial plant biomass [14]. BCF in stem and roots during day 21 was calculated for each Ni concentrations (2, 5, 10 mg/L). The BCF was estimated as the ratio of the metal concentration in the plant (mg kg^{-1} of dry weight) to the metal concentration in the growth medium (mg L^{-1}) [15], according to based on the following Equation (3) [16].

$$BCF = \frac{C_{\text{Ni plant}}}{C_{\text{Ni water}}} \qquad \ldots (3)$$

Where,

$C_{\text{Ni plant}}$ is the concentration of nickel in the plant (mg/g),

$C_{\text{Ni water}}$ is the concentration of nickel in water (mg/L).

Translocation factor (TF) is calculated to know the ability of plant to translocate metal from media by roots to shoots. TF is computed by dividing the Ni concentration in the plant's stem over Ni concentration in the plant's root (mg g^{-1} of dry weight) as shown in Equation (4) [15].

$$TF = \frac{C_{\text{Ni stem}}}{C_{\text{Ni root}}} \qquad \ldots(4)$$

Where,

$C_{\text{Ni stem}}$ is the Ni concentration in stem (mg/g),

$C_{\text{Ni root}}$ is the Ni concentration in the root (mg/g).

If both BCF and TF are >1, it thus indicates the appropriateness of plants for phytoextraction mechanism; but, high BCF>1 and low TF<1 indicates appropriateness for phytostabilization mechanism [17].

3. Results and Discussions

3.1 Observation of Physical Parameters

During 21 days of phytotoxicity test, the selected physicochemical parameter was measured for aquarium with different mass ratio (0, 2,800 and 34,000) as shown in Table 2. Generally, the temperature increased in the test period depending on weather and varied from 19.9- 32.3°C for all treatments. The optimum temperature for plants growth and accumulation of heavy metal did not exceed 32.2˚C [18]. The pH for aquariums was ranged between 7.14 to 8.10 and 7.38 to 7.72 for aquariums with plants and without plants, respectively. According to Rana and Maiti 2018 [17], the neutral to slightly alkaline environment implies that metal immobilization in the plant rhizosphere and absorption through plant roots are two plausible routes for metal elimination [17]. The DO was ranged between 0.96 to 4.98 mg/L and 3.40 to 6.77 mg/L for treatment with plants and without plants, respectively. It is clearly demonstrated that treatment with plants was leading to reduce the DO in the water media, may be due to rhizosphere zone (plant-bacteria interaction) [19].

TDS are the measurement of inorganic salts in wastewater, which ranged between 122.10 to 255.00 mg/L for all treatment. The concentration of TDS was inconsistent from day to day because the system was not fully acclimatized. The depletion of oxygen in the water system is characterized by high nutrient content and low dissolved oxygen, which indicates that the aquatic organism is decomposing [20].

Table 2,
Variation of physical parameters in Phytotoxicity test in SSB system

	Parameter	Mass ratio 0	Mass ratio 2,800	Mass ratio 34,000
Ni = 2 mg/L	T (°C)	24.15-26.65	24.15-26.55	26.80-29.90
	pH	7.38-7.70	7.6-7.60	7.68-8.75
	DO (mg/L)	4.30-3.98	4.40-2.40	4.80-2.54
	TDS (mg/L)	122.10-242.50	133.75-235	135.45-255
Ni = 5 mg/L	T (°C)	24.15-26.65	24.05-26.25	28.10-27.30
	pH	7.55-7.69	7.14-7.76	7.52-8.10
	DO (mg/L)	4.36-3.46	4.30-1.84	4.61-2.23
	TDS (mg/L)	127.15-235.00	126.15-235	125.20-236.00
Ni = 10 mg/L	T (°C)	24.20-26.75	24.15-26.15	26.55-28.30
	pH	7.68-7.72	7.26-7.77	7.64-8.64
	DO (mg/L)	4.59-3.52	4.58-0.95	4.98-2.22
	TDS (mg/L)	120.20-235.00	133.55-231.50	134.24-233.80

3.2 Ni removal from water in sub-surface batch system (SSB)

The concentrations of Ni using three mass ratios (0, 2,800, and 34,000) during experiment period are shown in Figure 3. The decreasing in Ni concentrations were 1.9-1.7, 1.9-0.31 and 1.9-0.25 mg/L; 4.7-4.1, 4.7-1.07 and 4.7-0.14 mg/L; and 9.3-0.6, 9.3-2.04 and 9.3-0.4 mg/L, for Ni concentrations (2, 5, and 10 mg/L) to each mass ratio 0, 2,800, and 34,000, respectively.

The reduction of Ni concentration were due to several reasons including phytoremediation mechanisms (phytodegradation, phytoextraction, phytostabilization) [21] and physical mechanisms (adsorption, precipitating) [22]. Ni removal percentages were calculated for each week within different mass ratios (0, 2,800, 34,000) and three concentrations throughout 21 days. For the mass ratio of 0, the removal rate was low because there was no plant in the aquarium. For the mass ratio of 2,800, the removal was 31-83.6%, 35.7-77.2%, and 25.9-78.0% for Ni concentrations of 2, 5, and 10 mg/L, respectively. The mass ratio of 34,000, the removal ranged between 45.7-86.8%, 35.9- 97%, and 34.4-95.6% for Ni concentrations 2, 5, and 10 mg/L, respectively. From the obtained results As a result of the removal rates of the three mass ratios (0, 2,800, 34,000) it was found that the highest removal occurred at the mass ratio of 34,000 and Ni concentration of 5 mg/L which was 97.0% on day 21. These results declare the capability of *I. herbstii* to enhance and accelerate the removal of heavy metal from contaminated water. A previous study by Pandey et al. 2007 [23], stated the ability of plant (*Calotropis procera*) to remove 250 mg/L Ni pollutants with 85% sorption efficiency from aqueous solution.

In an earlier research,by Alyazouri et al. 2014 [24], they was exceeded 90% for 5.1 mg/L Ni concentration in wetland which provide long term treatment. The removal of Ni in the aquarium without plant (CC) is due to the biological, physical, and chemical processes that occurred within substrate media[23].

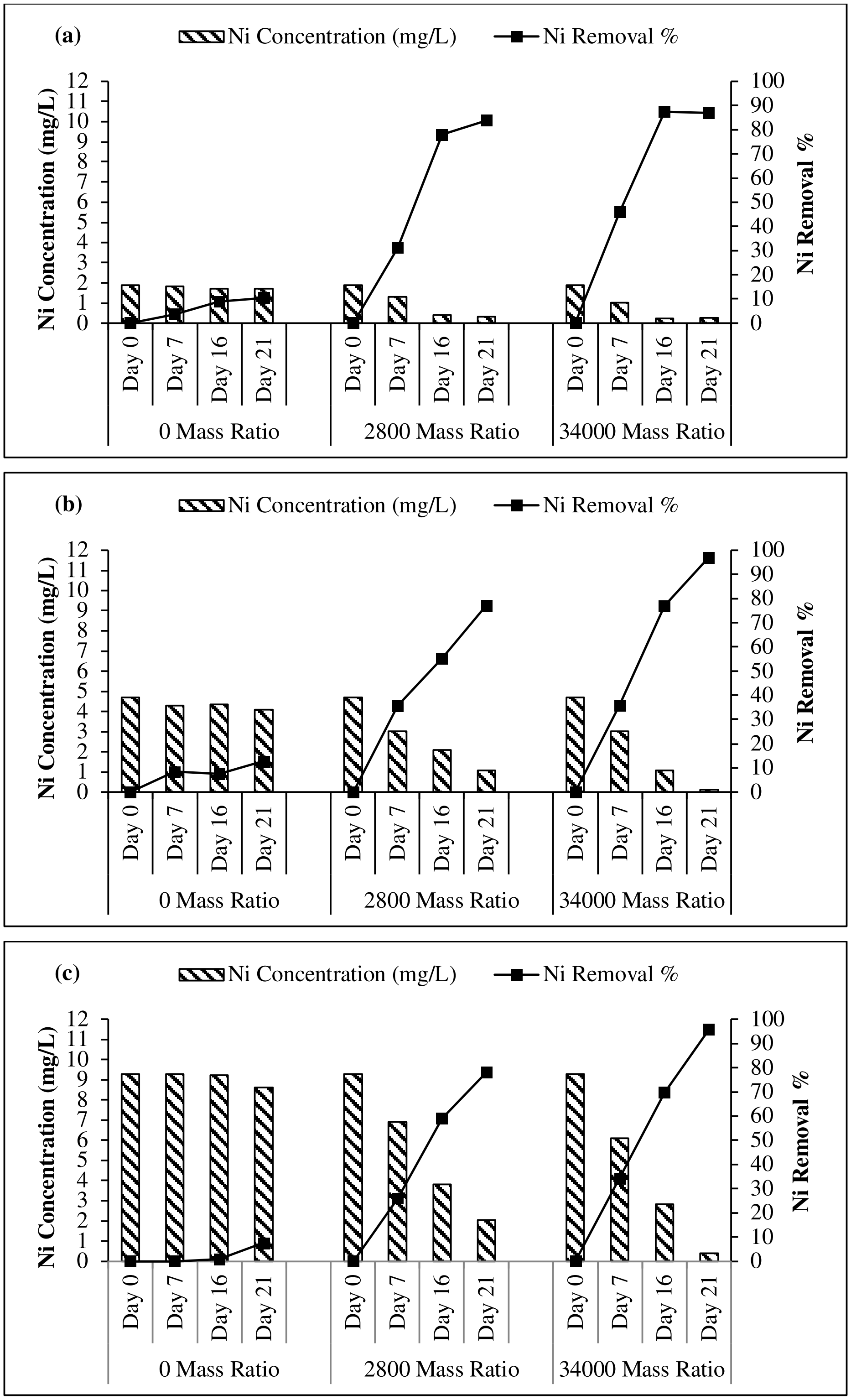

Fig. 3. Ni concentrations and removal percentage by *Iresine herbstii* during 21 day and mass ratio (0, 2800, 34000) (a) 2 mg/L, (b) 5 mg/L and (c) 10 mg/L

3.3 Accumulation of Ni in *Iresine herbstii*

After the digestion process, Ni accumulation in plant stems and roots, using three different Ni concentrations, are displayed in Figure 4. The highest accumulations of nickel were 48.99 mg/g and 12.89 mg/g in the root and stem of *I. herbstii* at 10 mg/L Ni concentration, respectively. According to Alyazouri et al. [25], the phrase "hyper accumulator" was coined to describe the tree of Sebertia acuminates accumulation of Ni in dry leaf tissue at levels greater than 1000 mg/kg. While based on Aran et al. [15], during 28 days of exposure, Ni accumulation in leaves and roots of large floating plants grew significantly by increasing exposion's time and metal concentration for various treatments. to Table 3 presents the almost BCF>1 and TF<1 which indicating that the potential of *I. herbstii* roots to absorb Ni through phytostabilization of Ni pollutants [26].

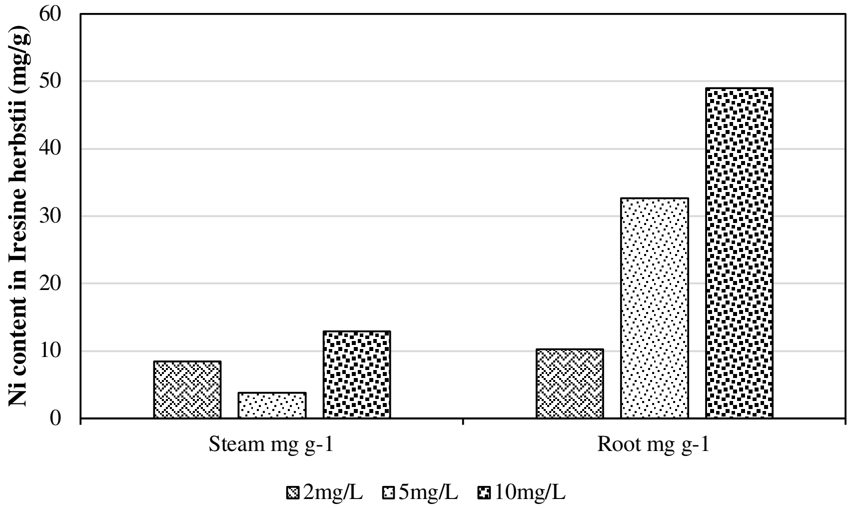

Fig. 4. Nickel in *Iresine herbstii.*

Table 3,
BCF and TF of Ni in the *Iresine herbstii* after 21 days of exposure

Ni concentration (mg/L)	BCF in Stem	BCF in Root	TF
2 mg/L	4.224	5.129	0.823
5 mg/L	0.750	6.521	0.115
10 mg/L	1.289	4.899	0.263

4. Conclusion

The current study reports successful green technology by using renewable natural materials, which are eco-friendly and cheap. The study of the phytoremediation using *Iresine herbstii* was successfully conducted to remediate contaminated water with Ni. The highest removal during the 21-day exposure was 97.0% and 95.6% for mass ratios of 3,400 for Ni concentrations of 5 and 10 mg/L, respectively. Therefore, From the results, it can be concluded that the removal efficiency with a mass ratio of 34,000 is Greater than the mass ratio of 2,800. Moreover, the BCF values of *I. herbstii* roots were higher than 1, ranging from 4.89 to 6.52 thus is considered a which a good accumulator and suitable for both phytoextraction and phytostabilization., This study proves that the possibility of using *I. herbstii* to Ni phytoremediation of from industry wastewater due to their availability and low cost for treatment.

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تأثير نسبة الكتلة على المعالجة النباتية للمياه الملوثة بالنيكل

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الخلاصة

استخدام النبات بمعالجة المياه هو أحد التكنولوجية الخضراء ضمن البيئة المستدامة .تم في هذه الدراسة اختبار السمية النباتية من خلال تعريض نبات دم العاشق (Irasen herbstii) لإزالة المعادن الثقيلة من المياه الملوثة بعنصر النيكل بنسب كتل نبات مختلفة ($R_{p/Ni}$) لمدة ٢١ يوم في نظام دفعات تحت السطح. خلال فتره التعرض كانت الأزالة لتراكيز النيكل المختلفة (٢,٥,١٠ ملجم/ لتر) ونسب الكتل للنبات ٢٨٠٠,٣٤٠٠٠ (78% ,77.2% ,83.6% و ,86.8%) (95.6% ,97% على التوالي . بالنسبة للنتيجة النهائية التي تم الحصول عليها من خلال الشرح أعلاه وجد أنه اعلى أزاله كانت عند نسبه الكتلة للنبات ٣٤٠٠٠ وتركيز ٥ ملجم /لتر والتي كانت (٩٧%) عند اليوم ٢١. تم فحص آلية تراكم المعادن للنباتات باستخدام عامل التركيز الأحيائي (BCF) وعامل الانتقال (TF) للمعادن التي أشارت إلى أن نبات الإيريسين مناسب للتثبيت النباتي للنيكل (1 < BCF و 1 > TF). لهذا السبب، كان لديه القدرة على معالجة مياه الصرف الصحي الملوثة بالمعادن الثقيلة مما يدل على أن Iresine herbstii هو نبات محتمل لإزالة Ni من المياه الملوثة.