Temperature dependence for purification of leachate containing heavy metals by phytoremediation using the artificial channel

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Abstract. Concentrations of heavy metals leach from soil and rock excavated at civil engineering construction sites occasionally exceed the environmental criteria value in Japan. The phytoremediation is one of the techniques for cleaning up contaminated environments. The Eleocharis acicularis is tolerant plant of a wide variety of heavy metals, and it absorbs and accumulates these metals and has been proven to be effective in mine effluent treatment. In this study, we conducted a purification experiment using an artificial channel to know the ability of the E. acicularis to absorb and accumulate heavy metals due to differences in temperature. The drainage containing arsenic flowing out of the embankment flowed into the artificial channel at different periods of average temperature. As a result of experiments, the arsenic content of the E. acicularis were confirmed increasing in 3.4 mg/kg in the summer and 2.3 mg/kg in the winter. These values are corresponding with 0.8% in the summer and in 0.3% in the winter for the arsenic gross weight of the displacement according to each season. Thus, the arsenic absorption ability of the E. acicularis was able to grasp by the artificial channel experiment.

1. Introduction
An engineering enterprise may temporarily store excavated soil, sand, and rocks containing heavy metals outdoors. Water containing heavy metal ions and other harmful materials may leach from the exposed excavated soil, sand, and rocks due to rainfall. It is exceeding the limit of the Environmental Quality Standard in Japan. This leaching water must be treated appropriately from the viewpoint of preventing harmful effects on the human body and peripheral environment.

An environmental contamination remedial technique using the phyto-heavy-metal-absorbing effect has gained attention in recent years [1-3]. Although this technology has disadvantages, such as it can only restore an area of the phyto-rhizosphere and requires time for phyto-growth, the low cost and lower energy cost are advantages. However, the application of the technology requires rational utilization methods corresponding to the phyto-growth conditions and quality of water to be treated.
An experiment to study this method was performed twice, each time in a season with different temperature, in the following manner: in a site of the embankment banked with excavated rocks, the artificial channel is covered with *E. acicularis*, a plant in the Cyperaceae family with the capability to absorb heavy metals and other harmful elements, and the leaching water containing arsenic constantly flows in from the embankment. This paper discusses the results of outdoor experiments to grasp the ability to absorb and accumulate heavy metals due to differences in temperature by *E. acicularis*.

2. Outline
Figure 1 shows the artificial channel. The artificial channel, made of vinyl chloride, is 30 cm in width and 20 meters in length, with a 0.5% watering slope. The *E. acicularis* is planted in the artificial channel covered an area of 5.8 m², and the weight of the wet plants was 23.2 kg. The experiment was performed in two terms with different ambient temperatures: the first term was 81 days from August 4 to October 24, 2016, and the second term was 107 days from October 25, 2016, to February 9, 2017. The *E. acicularis* was renewed for the second term.

The average ambient temperature and average water temperature were 20.5 and 18.7°C in the first term, and 4.2 and 9.7°C in the second term. Moreover, the leaching water was made to flow into the artificial channel at a rate of 0.5 litters/min. The total inflow was 41,247 litters in the first term and 36,590 litters in the second term. At the times of initiation and completion of the experiment, the arsenic concentrations of the leaching water and *E. acicularis* were analysed. From the analysis results, the amount of arsenic absorption of the *E. acicularis* was compared to the total arsenic amount in the leaching water made to flow in during each experimental term was calculated, and the effect caused by the difference in temperature was studied.

3. Method of analysis
The arsenic concentration of the leaching water was adjusted with nitric acid to a concentration of 1% after filtration and analysed with high-frequency inductively-coupled mass spectrometry. The *E. acicularis* was, after being sampled, fully washed with ultra-pure water, dried for two days at 40°C with a dryer, and milled to a fine powder with a cutter-type mill. After that, to change the powder sample to a solution for the analysis, 0.1 mg of powder was put into a 100-ml polytetrafluoroethylene container, and 2 ml of about 30% hydrogen peroxide and 5 ml of 61% nitric acid were added. That mixture was then heated in a microwave in three steps, at 150°C for 5 minutes, 190°C for 15 minutes, and 50°C for 10 minutes, and then the sample was analysed with high-frequency inductively-coupled mass spectrometry.
4. Experimental results

4.1. Results of the first term
The analysis results of the first term are shown in Table 1. The results of analysis of the arsenic concentrations of leaching water were 0.028 mg/litter at the initiation time and 0.029 mg/litter at the completion time, which showed no significant change. On the other hand, the arsenic concentrations of the *E. acicularis* was 0.2 mg/kg at the initiation time and 3.6 mg/kg at the completion time, which confirmed an increase of 3.4 mg/kg.

4.2. Results of the second term
The analysis results of the second term are shown in Table 2. The results of the analysis of the arsenic concentrations of leaching water were 0.029 mg/litter at the initiation time and 0.028 mg/litter at the completion time, which showed no significant change. On the other hand, the arsenic concentrations of the *E. acicularis* was 0.2 mg/kg at the initiation time and 2.5 mg/kg at the completion time, which confirmed an increasing of 2.3 mg/kg, which is less than that of the first term.

**Table 1.** The analysis results of the first term.

| element | concentration of leachate (mg/L) | concentration of the *Eleocharis acicularis* (mg/kg) |
|---------|---------------------------------|---------------------------------------------|
| As      | 0.028                           | 0.2                                         |
| Mn      | 0.091                           | 35                                          |
| Fe      | <0.002                          | 384                                         |
| Zn      | <0.001                          | 580                                         |
| Mo      | 0.286                           | 2.1                                         |
| Sr      | 0.841                           | 24.4                                        |
| P       | 0.045                           | 3,890                                       |
| Mg      | 3.77                            | 1,210                                       |
| Na      | 93.5                            | 747                                         |
| Ca      | 268                             | 4,230                                       |
| K       | 12.2                            | 10,800                                      |

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![Figure 1. Outline of the artificial channel.](image-url)
Table 2. The analysis results of the second term.

| element | start (mg/L) | end (mg/L) | concentration of the \( E. \text{acicularis} \) (mg/kg) |
|---------|--------------|------------|--------------------------------------------------|
| As      | 0.029        | 0.028      | As 0.2                                          |
| Mn      | 0.145        | 0.003      | Mn 19                                           |
| Fe      | <0.002       | 0.004      | Fe 611                                          |
| Zn      | <0.001       | <0.001     | Zn 73.1                                         |
| Mo      | 0.248        | 0.285      | Mo 3.5                                          |
| Sr      | 0.803        | 0.966      | Sr 25.0                                         |
| P       | 0.047        | 0.021      | P 3,290                                         |
| Mg      | 3.83         | 3.80       | Mg 725                                          |
| Na      | 89.1         | 95         | Na 666                                          |
| Ca      | 245          | 276        | Ca 4,760                                        |
| K       | 11.4         | 12.1       | K 6,210                                         |

5. Discussions
The amount of arsenic absorption of the \( E. \text{acicularis} \) was compared to the total arsenic amount in the leaching water made to flow in during each experiment term was calculated, and the absorbency of the \( E. \text{acicularis} \) in the terms with different temperatures was studied.

5.1. Amount of arsenic absorption of the \( E. \text{acicularis} \) in the first term

5.1.1. Calculation conditions.
Experiment days: 81 days (August 4 to October 24, 2016)
Amount of the total inflow of the drainage to the artificial channel: 36.6 m\(^3\) (36,590 litters)
Arsenic concentration of the effluent: 0.028 mg/litter
Arsenic concentration of the \( E. \text{acicularis} \): 3.4 mg/kg (3.6 at the final time - 0.2 at the initial time)
Weight of the covered \( E. \text{acicularis} \) (dry weight at the final time): 2.4 kg
Area covered on artificial channel by the \( E. \text{acicularis} \): 5.8 m\(^2\)

5.1.2. Calculation results.
Total arsenic amount = 36,590 litters x 0.028 mg/litter = 1,025 mg
Amount of arsenic per day = 1,025/81 = 13 mg/day
Amount of arsenic absorption of \( E. \text{acicularis} \) per day = 3.4 mg/kg/81 days = 0.04 mg/kg/day
Amount of arsenic absorption of \( E. \text{acicularis} \) in the artificial channel per day
\[ = 0.04 \text{ mg/kg/day} \times 2.4 \text{ kg} = 0.10 \text{ mg/day} \]
The ratio of capability to absorb the arsenic contained in the effluent into the artificial channel by \( E. \text{acicularis} \) in the first term
\[ = 0.10 \text{ mg/day} / 13 \text{ mg/day} = 0.008 \]
The amount of the arsenic absorption of the \( E. \text{acicularis} \) per day per unit area = 0.10 mg/day / 5.8 m\(^2\)
\[ = 0.02 \text{ mg/day-m}^2 \]
From the above results, in the first term, the \( E. \text{acicularis} \) absorbed 0.8% (8.2 g) of the arsenic. Moreover, the amount of the arsenic absorption of the \( E. \text{acicularis} \) per day per unit area under the temperature conditions of the first term was grazed.

5.2. Amount of arsenic absorption of the \( E. \text{acicularis} \) in the second term
5.2.1. Calculation conditions.
Experiment days: 107 days (October 25, 2016, to February 9, 2017)
Amount of the total inflow of the drainage to the artificial channel: 41.2 m\(^3\) (41,247 litters)
Arsenic concentration of the effluent: 0.028 mg/litter
Arsenic concentration of the \(E.\) acicularis: 2.3 mg/kg (2.5 at the final time - 0.2 at the initial time)
Weight of the covered \(E.\) acicularis (dry weight at the final time): 1.4 kg
Area covered on artificial channel by the \(E.\) acicularis: 5.8 m\(^2\)

5.2.2. Calculation results.
Total arsenic amount = 41,247 litters x 0.028 mg/litter = 1,155 mg
Amount of arsenic absorption of \(E.\) acicularis per day = 1,155/107 = 11 mg/day
Amount of arsenic absorption of \(E.\) acicularis per day in the artificial channel per day
= 0.02 mg/kg/day x 1.4 kg = 0.03 mg/day
The ratio of capability to absorb the arsenic contained in the effluent into the artificial channel by \(E.\) acicularis in the second term
= 0.03 mg/day / 11 mg/day = 0.003
The amount of the arsenic absorption of the \(E.\) acicularis per day per unit area = 0.02 mg/day / 5.8 m\(^2\)
= 0.003 mg/day-m\(^2\)
From the above results, in the second term, the \(E.\) acicularis absorbed 0.3% (3.5 g) of the arsenic. Moreover, the amount of the arsenic absorption of the \(E.\) acicularis per day per unit area under the temperature conditions of the first term was also grazed.

6. Conclusions
This experiment revealed the following findings.
- The experiment of purifying the water leaching from an embankment containing arsenic exceeding the limit of the Environmental Quality Standard was performed under different temperature conditions using \(E.\) acicularis planted in the artificial channel. As a result, the amount of arsenic absorption of the \(E.\) acicularis increased by 3.4 mg/kg (from 0.2 mg/kg of the initial concentration to 3.6 mg/kg of the final concentration) in 81 days under an ambient temperature of 20.5°C (average water temperature of 18.7°C). On the other hand, the amount of arsenic absorption of the \(E.\) acicularis increased by 2.3 mg/kg (from 0.2 mg/kg of the initial concentration to 2.5 mg/kg of the final concentration) in 107 days under an ambient temperature of 4.2°C (average water temperature of 9.7°C), which was less than that of the term when the average temperature was higher.
- The absorbency of the \(E.\) acicularis was calculated with respect to the total arsenic amount of the leaching water flowing into the artificial channel. The results were 0.020 mg/day/m\(^2\) in 81 days under an average ambient temperature of 20.5°C (average water temperature of 18.7°C), and 0.003 mg/day/m\(^2\) in 107 days under an average ambient temperature of 4.2°C (average water temperature of 9.7°C). The capability to absorb arsenic using the artificial channel was ascertained.
- In addition, the \(E.\) acicularis capability to absorb the arsenic, that is the ratio of the amount of absorbed arsenic to the total amount of arsenic in the leaching water, was 0.8% under the average ambient temperature of 20.5°C (average water temperature of 18.7°C) in 81 days, and 0.3% under the average ambient temperature of 4.2°C (average water temperature of 9.7°C) in 81 days, which suggests that the amount of absorption differs depending on the temperature.
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