PHYTOREMEDIATION OF URANIUM FROM WASTEWATER USING WATER HYACINTH (EICHHORNIA CRASSIPES)

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Abstract

In addition to uranium radionuclides, wastewater from nuclear fuel manufacturing and radioactive waste treatment processes also contains non-radioactive compounds of phosphorus and nitrogen. To create the experimental framework, two fifty-liters aquariums were used: one for the experiment and the other as a control. Each tank was filled with 17.5 liters of water. In the first aquarium, industrial wastewater rich in phosphorus and nitrogen nutrients was used. In the second aquarium (control), household water enriched with chemical fertilizer for leafy plants, fertilizer rich in nitrogen and phosphorus, was placed. A water hyacinth stolon was placed in each aquarium. Over a month and a half, the plants' moist mass increased 65 times, while the amounts of nitrogen, phosphorus, and uranium in the water reduced by about 80%. According to the experimental data, 32% of the phytoremediated uranium in the aquarium water was bioaccumulated by the water hyacinth, while the remaining 68% was fixed in algae that developed in the water hyacinth growth medium, mud, and on the aquarium walls.

Keywords: *Water hyacinth, Phytoremediation, Wastewater*

Introduction

The manufacturing technology of CANDU-type fuel bundles involves the processing of the "yellow-cake" raw material through wet extraction with precipitation from ammonium diuranate or uranyl nitrate hexahydrate using nitric acid.

The treatment of liquid waste contaminated with natural uranium resulting from the manufacturing of nuclear fuel (processing uranium concentrate from plant R to obtain sinterable UO_2 powder and processing UO_2 powder to manufacture sintered UO_2 pellets; processing UO_2 pellets) involves a technology based on the selective precipitation of natural uranium as uranyl phosphate through the action of trisodium phosphate at neutral pH.

As a result, industrial waters discharged from both processes (nuclear fuel manufacturing and the treatment of waste contaminated with natural uranium) are expected to contain significant quantities of phosphorus and nitrogen ions, as well as uranium.

This study aimed to investigate the removal of phosphorus and nitrogen compounds from wastewater generated during the technological processes of producing CANDU nuclear fuel and treating liquid waste contaminated with natural uranium. Advanced purification technologies, particularly biotechnologies, were used for this purpose. Environmental depollution biotechnologies encompass all methods and techniques for biological purification of waste or polluted waters, including bioremediation methods involving plants or microorganisms [1]. The biological absorption of radionuclides by aquatic organisms and other terrestrial or aquatic vegetation plays a crucial role in lowering radioactive pollutants. Phytoremediation is considered as a viable solution for cleaning contaminated radioactive environments, providing a simple, environmentally friendly, and energy-efficient method for remediating radioactive soils and waters.

Phytoremediation mechanisms for managing radioactive waste include biodegradation, phytoextraction, phytodegradation, and phytostabilization. Since radionuclides are not biodegradable, phytoextraction and phytostabilization are the primary mechanisms for restoring radioactively contaminated environments [2]. Phytoextraction is the process by which plant roots absorb radionuclides from the surrounding environment, and their subsequent translocation and accumulation in the stem and leaves. The selection of plants for phytoremediation is influenced by a number of factors, including the radioactive waste characteristics, growth conditions, vegetation community composition, radionuclide concentrations, and plant biomass.

Water hyacinth (Eichhornia crassipes) is widely used in wastewater phytoremediation due to its effectiveness in bioaccumulating heavy metals [3]. Similarly, it can be used to clean radioactively contaminated water sources, according to specialized literature.

Description of the performed experiments

The paper presents some results of a study on reducing the primary pollutants from liquid waste contaminated with natural uranium using water hyacinth (Eichhornia crassipes) as a phytoremediator.

To investigate the bioaccumulation of nitrogen, phosphorus, and uranium by water hyacinth (Eichhornia crassipes) in an aqueous environment, several experiments were conducted to track variations of these parameters during the plant's growth.

The proposed experiments were carried out in three stages. First, attempts were made to acclimatize the plant to laboratory conditions. Two 50-liter aquariums were used, one for the experiment and the other as a control. Each tank was filled with 17.5 liters of water. The first aquarium contained industrial water rich in phosphorus and nitrogen nutrients from the Radioactive Waste Treatment Station of RATEN ICN Pitesti, while the second (control) one contained household wastewater from the Treatment Plant enriched with chemical fertilizer for leafy plants, whose content was high in nitrogen and phosphorus.

Each aquarium received a water hyacinth stolon ranging in size from 4-5 cm and weighing roughly 3-4 grams.

After several trials adjusting the plant's development, optimal growth conditions for water hyacinth were established by adding nutrients with high nitrogen and phosphorus content. Additionally, an amount of uranium was added to assess uranium bioaccumulation by water hyacinth (Eichhornia crassipes).

At the same time, water hyacinths were also placed in basins containing household wastewater from the RATEN ICN Treatment Plant. Figure 1 depicts the water hyacinth growth over time in the RATEN ICN Pitesti Treatment Plant's household wastewater basin.

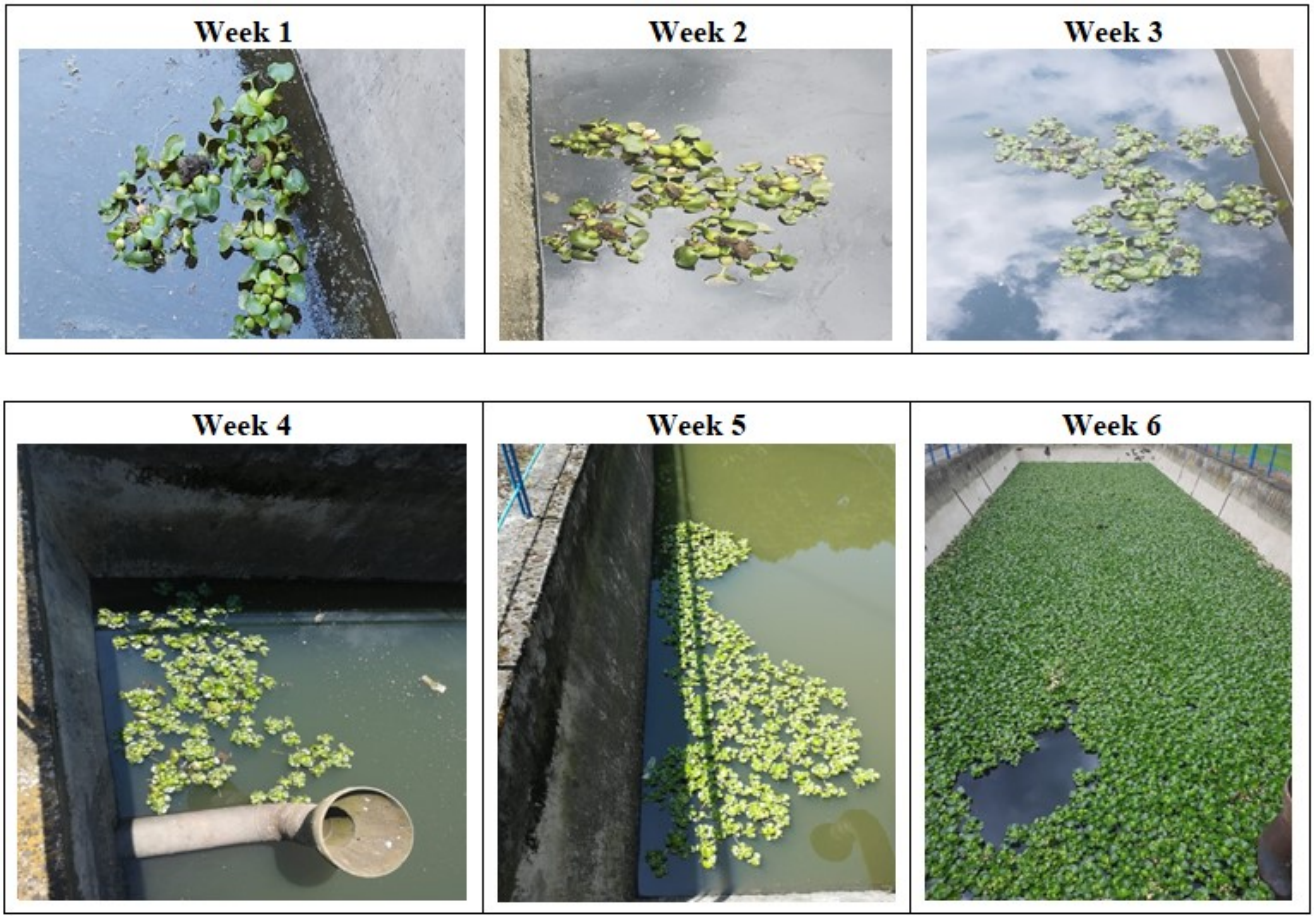


Fig. 1. Evolution of water hyacinth in the household wastewater basin from the RATEN ICN Treatment Plant

The second stage involved weekly monitoring of phosphorus, nitrogen, and natural uranium levels in the controlled environment for water hyacinth (Eichhornia crassipes) growth. Over the course of a month and a half, the plant's growth was tracked weekly, and water analysis was performed to monitor key parameters of interest such as total phosphorus, total nitrogen, and natural uranium.

The plant grew rapidly due to the favorable environmental factors for water hyacinth development (such as warmth, light, and nutrient-rich water). As a result, within a week, the experimental stolon had doubled in size.

The stolon under experimentation began weighing 5.7 gram (wet mass) and multiplied over the course of a month and a half, reaching a total plant weight in the aquarium of 374 grams, covering the entire tank surface. Over 8 weeks, the moist mass of the plants increased 65-fold.

Figure 2 illustrates the progress of water hyacinth in the laboratory experiments over time.

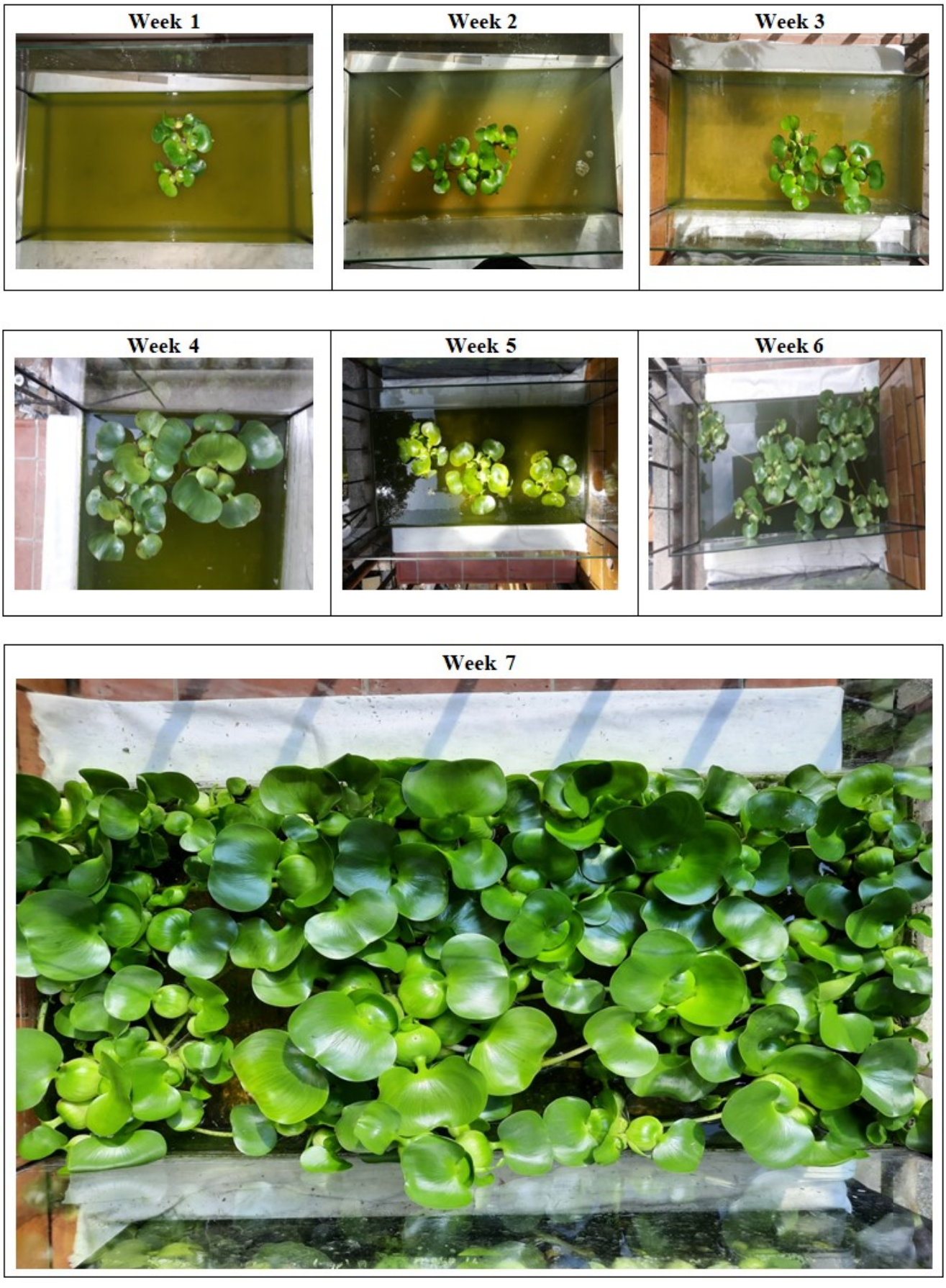


Fig. 2. Evolution of water hyacinth in the laboratory tests

Results and discussion

Tabel 1 shows the results of weekly measurements of natural nitrogen, phosphorus, and uranium levels in the controlled growth medium of water hyacinth.

As the water hyacinth grows, the concentrations of nitrogen, phosphorus, and natural uranium in the plant's environment decrease as the water hyacinth bioaccumulates these elements.

Table 1. Weekly measurements of nitrogen, phosphorus and natural uranium in the water hyacinth environment

Week	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Natural uranium (mg/l)
Week 1	95.5 ± 9.5	17.90 ± 1.8	2.014 ± 0.60
Week 2	155 ± 15.5	16.40 ± 1.6	2.196 ± 0.65
Week 3	95.3 ± 9.5	16.00 ± 1.6	2.092 ± 0.62
Week 4	114 ± 11.4	10.40 ± 1.0	1.380 ± 0.41
Week 5	75.7 ± 7.5	9.58 ± 0.9	0.900 ± 0.27
Week 6	65.3 ± 6.5	7.34 ± 0.7	0.537 ± 0.16
Week 7	35.4 ± 3.5	6.60 ± 0.6	0.414 ± 0.12
Week 8	12.3 ± 1.2	3.78 ± 0.3	0.238 ± 0.07

Figures 3, 4, and 5 depict the weekly variations in the concentrations of the three parameters of interest within the water hyacinth's controlled growth environment.

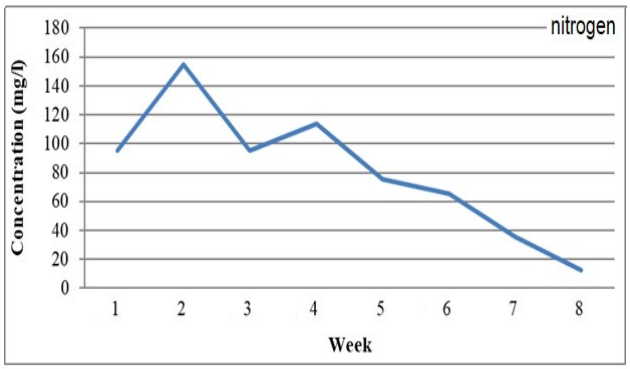


Fig. 3. Weekly variation of total nitrogen from the controlled growth environment of water hyacinth

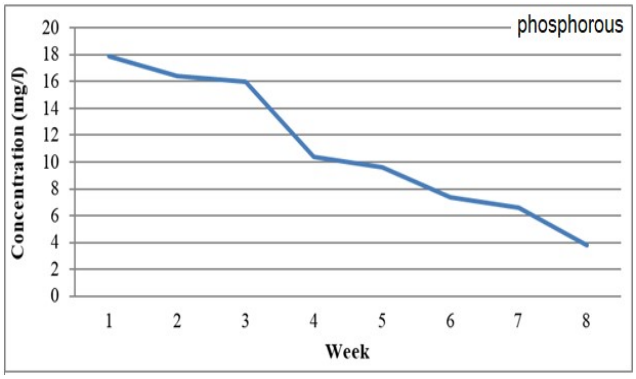


Fig. 4. Weekly variation of total phosphorous from the controlled growth environment of water hyacinth

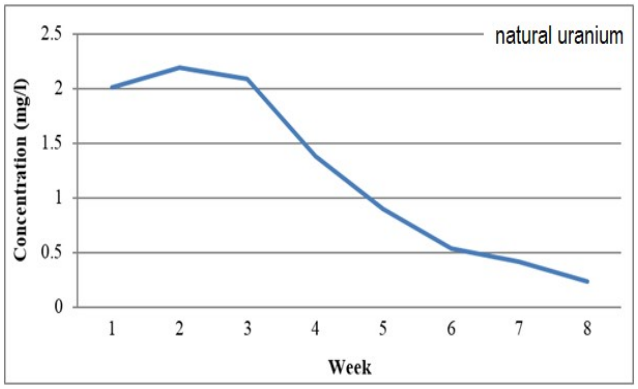


Fig. 5. Weekly variation of natural uranium from the controlled growth environment of water hyacinth

Table 2 shows the concentrations of the three parameters of interest at the beginning of the experiment and after eight weeks of water hyacinth growth, and the corresponding phytoextraction yield values.

Table 2. Phytoextraction yield for the nitrogen, phosphorus and natural uranium in the water hyacinth environment

Parameter	Initial concentration (mg/l)	Final concentration (mg/l)	Phytoextraction yield (%)
Total Nitrogen	95.5 ± 9.5	12.3 ± 1.2	87
Total Phosphorus	17.90 ± 1.8	3.78 ± 0.3	79
Natural uranium	2.014 ± 0.60	0.238 ± 0.07	88

During the eight-week experiment, along with the water hyacinth, two types of algae grew in the aquarium:

- Microscopic, unicellular green algae that float in the water and cause it a green tint;
- Multicellular, filamentous, horsehair-like algae that adher to the aquarium's walls.

Due to the presence of these algae, while assessing the balance of nitrogen, phosphorus, and natural uranium concentrations in the aquarium, it's important to take into consideration that some of these elements are fixed or absorbed by the algae.

In the third stage, following the end of the experiment, measurements were conducted to determine the uranium distribution in the plants, aquarium water, and activated sludge created the water hyacinth growth period.

To evaluate uranium bioaccumulation by the water hyacinth, all plants in the aquarium were harvested at the end of the experiment. After drying in an oven at 105 °C, a dry mass of 22.2 grams was obtained. The plants were then calcined at 450 °C to determine their uranium content, yielding a total ash of 2.88 grams. Spectrophotometric analysis of the natural uranium concentration in the ash revealed a value of 2.596 mgU/g ash.

According to calculations, the total amount of uranium bioaccumulated by the water hyacinth was 7.47 mg, equivalent to 336 mg of uranium per kilogram of dried water hyacinth.

After the water hyacinths were removed from the aquarium, the water and algae were processed to assess their uranium content. The total measured uranium amount (m_final aquarium = m_algae + m_final water) was 19.95 mg (see Table 3). This value represents the sum of the uranium absorbed or fixed in the algae (m_algae) and the uranium remaining in the aquarium water at the end of the experiment (m_final water).

At the end of the experiment, the uranium content in the water was 0.238 mg/l, equivalent to 4.16 mg, indicating that 15.79 mg of uranium was absorbed or fixed in the algae.

Table 3. Final results on natural uranium content

No. crt.	Measuring	Uranium (mg)
1.	The initial amount of uranium in the aquarium water	35.2 ± 10.5
2.	The final amount of uranium in the aquarium water	4.16 ± 1.28
3.	The amount of uranium extracted by water hyacinth	7.47 ± 2.24
4.	Amount of uranium in water and algae (evaporation and calcination)	19.95 ± 5.98

Based on the experimental data, out of the 23.26 mg of uranium phytoremediated, 7.47 mg (representing 32%) was bioaccumulated by the water hyacinth, and 15.79 mg (representing 68%) was fixed in the algae and on the walls of the aquarium.

Conclusions

Water hyacinth reduces uranium content in water by 32% during the phytoextraction process, with the balance being fixed in algae or active sludge created on the aquarium bottom.

During the 8-week experiment, water hyacinth bioaccumulated a total amount of 7.47 mg of uranium, which is equivalent to 336 mg of uranium per kilogram of dry plant.

Water hyacinth proliferates rapidly and produces a large biomass. According to specialized literature, some of the water hyacinth notable properties, such as a very high productivity rate (doubling in 6 days), dense plant growth (10-50 kg wet weight/m^2), and a rapid growth rate (5-30 kg dry weight/m^2/day), enable it to significantly reduce nitrogen, phosphorus, and uranium concentrations in wastewater basins. A straightforward calculation, factoring in its growth rate, yields bioaccumulated uranium amounts ranging from 1.68 to 10.08 g/m^2/day.

The plant can be easily harvested, and after drying and calcination, the uranium can be recovered from the resulting ash.

A drawback in using the plant as a biological remediation agent for ponds contaminated with nitrogen, phosphorus, and natural uranium is that it grows only during the hot summer months, limiting its applicability in wastewater treatment to a short and specific period.

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