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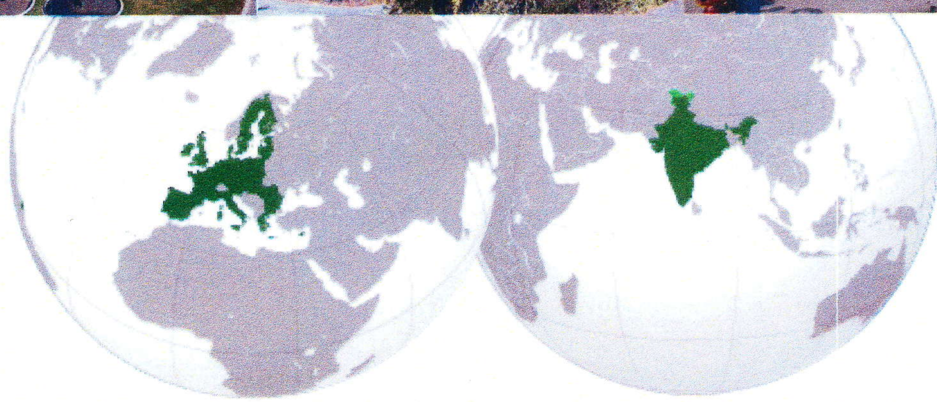

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# *Artificial Treatment Wetlands: An Alternative to Remove Arsenic From Water*

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***Abstract***

Arsenic can be removed from water through rhizofiltration using phytostabilizing plants. The performance of *Eleocharis macrostachya* in artificial or constructed wetlands for arsenic removal was determined at the prototype level. The concentrations of arsenic in the inlet water were maintained constant at five levels (0.05, 0.1, 0.2, 0.3 and 0.4 mg/L), and a flow rate of 130 L/d). Water samples were taken at the inlet and outlet of the wetlands during the entire testing period. Plant growth was also monitored to determine tolerance at the tested arsenic concentrations. The prototypes with plants were able to retain an average of 85 to 90% of the arsenic present in feed water containing concentrations in the range of 0.01 to 0.4mg/L. Plant reproduction values were above 116%, and no difference in growth size with respect to the control was observed. Results show that *Eleocharis macrostachya* tolerates high arsenic concentrations in flooded environments and behaves as a rhizofilterer retaining arsenic from water in artificial wetlands.

**Keywords**: arsenic; artificial wetlands; *Eleocharis macrostachya;* phytoremediation; water

## *Introduction*

Drinking water with high arsenic concentrations has caused serious health problems in many countries around the globe. Arsenic is known for being a carcinogen, mutagen, and an agent that deteriorates the immune system. Chronic exposure to drinking water with arsenic concentrations of 0.050 mg/L can increase the risk of cancer in humans by 13% (Pontius et al., 1994). Because of this, the World Health Organization (WHO) recommends a concentration of 0.010mg/L as the maximum since 1993.

Arsenic has been detected in many supplies of drinking water in Mexico; the state of Chihuahua, located in the semi-arid zone of northern Mexico, is one of the most affected states with naturally-occurring arsenic in underground water. Technologies for treating water polluted with arsenic are expensive, and produce secondary residue (Litter et al., 2012). Reverse osmosis is the most widely employed process for arsenic removal in drinking water, but it has the disadvantage of generating a great amount of rejected water (around 50% of the feed water) (USEPA, 2002). This issue and the system's high cost of operation make it economically prohibitive for many communities, especially in rural areas. It is therefore necessary to find innovative and low-cost alternatives for arsenic removal. Phytoremediation is a new technology that uses green plants to degrade organic compounds, stabilize and/or remove metals and metalloids (Litch et al., 1995 and Raskin et al., 1994). Artificial or constructed wetlands with sub-surface flow (CWs) have been used effectively for treating wastewater from city sewers, food processing, pulp and paper production, the textile industry, agriculture and leachate from landfills, among others (Kadlec and Knight, 1996, Vymazal et al., 2008). Despite these many applications, the use of these systems has not been considered for the production of drinking water. Arsenic can be removed from water through plants by the process of phytoextraction using hyperaccumulator plants, or it can be filtered and adsorbed by the roots through rhizofiltration using phytostabilizing plants. *Pteris vittata* is a plant species from the fern family reported to have a huge capacity for quickly hyper-accumulating arsenic in its leaves, up to concentrations above 22,000 mg/kg in a 6-week period (Ma et al., 2001). Later studies have demonstrated that other species of the *Pteris* genus also hyper-accumulate arsenic (Meharg, 2003, Zhao et al., 2002). Previous works have reported the potential of *Schoenoplectus americanus* and *Eleocharis macrostachya* for the removal of arsenic in constructed wetlands. *Eleocharis macrostachya* is a species with potential for use in rhizofiltration (Nuñez et al., 2007). The purpose of this study was to determine the tolerance of. *Eleocharis macrostachya* in the removal of arsenic from water, in constructed wetlands with submerged flow, at the prototype level.

## Material and Methods

### *1. 1 System design*

The experiment was performed using three wetland prototypes, operating with sub-surface flow. Two of them with plants (CW1 and CW2) and the third without plants, only with silty sand (CW3). A 0.35m deep (0.26m$^3$) bed composed of silty sand with a particle size between 0.07 and 4.7mm was used as support medium, and rough gravel (25-40 mm) was used at the entrance and exit. The plant species used for the study was *Eleocharis macrostachya*, collected in the surroundings of Chihuahua city. Different concentrations of water with Arsenic, 0.05, 0.1, 0.2, 0.3 and 0.4 mg/L, with a flow rate of 130 L/d were tested in the wetland prototypes to determine arsenic retention in each prototype.

### *1. 2 Sampling and analytical determination of arsenic*

Throughout the experiment, water samples were taken from the entrance and exit of the 3 prototypes. At the end of the experiment, significant samples of the plants and soil were taken to be analyzed and determine the arsenic contents. The determination of total arsenic in the digested samples was carried out using an atomic absorption spectrophotometer with hydride generator, (maker: GBC; model: Avanta Σ) for low concentrations (0.005-0.1 mg/L). Arsenic concentrations above 0.1 mg/L were measured by an inductively coupled plasma optical emission spectrophotometer (ICP-OES; maker: Thermo Jarrell Ash; model: AP-Duo Iris). Duplicate samples, certified standard (NIST 1573$^{rd}$), and blanks were used to ensure the quality of the analytical measurements. The arsenic recovery was 97 ± 2% for all samples and the reference materials.

*1. 3 Tolerance to arsenic by the plants.*

To determine the plants' physical behavior and test their acclimatization and tolerance to the different arsenic concentrations, the growth and reproduction of the transplanted individuals were monitored in different stages of the experiment. For reproduction monitoring, the individuals in each wetland were counted several times (beginning, during and at the end of the experiment). For the growth monitoring, three individuals of each group were randomly taken and identified; height was measured at the time of the transplant and at the end of the experiment. Bioconcentration and translocation factors were determined according to the criteria established in the literature (Fitz and Wenzel, 2002). Bioconcentration factors were calculated by dividing the concentration of the metalloid in the plant's phytomass (mg/kg) by the concentration of the element in the soil (mg/kg). The translocation factor was determined by dividing the concentration of the aerial parts (mg/kg) by the concentration in the phytomass of the root. The experiment was performed at the greenhouse level, with sunlight providing the only energy used to grow the plants.

## *Results*

The average arsenic removal percentages for CW1 and CW2 during the time of the experiment were between 85 and 90%, respectively, while CW3 presented an average removal percentage of only 46%. The purpose of varying the inlet As concentration in the system was to observe the performance of the prototypes with and without plants. Even with the increase of concentration in arsenic at the entrance, CWs with plants were able to keep As concentrations in water at the output below 25 µg/l, (NOM 127, Mexican regulations for drinking water) (Figure 1).

The gradual increment of the arsenic concentration at the exit of CW3 (the wetland without plants) shows that the support medium (silty sand) was beginning to saturate after 9 weeks for the tested As concentrations. The increase in arsenic concentration at the outlet of the prototype CW3 is clearly higher (Figure 2). The efficiency in trapping arsenic decreased for an inlet concentration of 100 mg/L preceded by a concentration of 400 mg/L. This shows that the prototype without plants has a lower capacity to absorb variations in As concentration, while the wetlands with plants (CW1, CW2) could keep the exit concentrations below 0.025 mg/L.

The concentrations and saturation time of the plants were not determined in this study, which is why further studies must be performed to determine these parameters. The analysis carried out at the end of the experiment shows that the plants' roots contained the highest arsenic concentrations, with a maximum value of 48 mg/kg. The shoots presented the lowest values, most of them below 1 mg/kg, indicating that *E. macrostachya* is a stabilizer rather than a hyperaccumulator. The latter, according to the literature are plants that accumulate As concentrations in their aerial parts to concentrations higher than 1000 mg/kg (Ma *et al.*, 2001).

The results of the different countings performed throughout the experiment show that the plants greatly increased their population with respect to the initial number of individuals; average reproduction values were above 116%, and the size of the individuals was 200 cm.

The bioconcentration factor was 3.72, and the translocation factor was 0.027. The bioconcenration value produced by this study agrees with the values obtained in previous studies, in which *E. macrostachya* was subjected to concentrations of 3, 6 and 9 mg/L and bio-concentration factors of 3.45, 3.00 and 2.76 were obtained (Nuñez et al., 2007). The plants' relative rates of growth and reproduction indicate that *E. macrostachya* is tolerant to high concentrations of arsenic. *E. macrostachya* confirms to be a rhizofiltrator species, which retains in its roots most of the arsenic removed from water; this represents a great advantage for use in constructed wetlands, since it avoids the danger of affecting other organisms in the food chain.

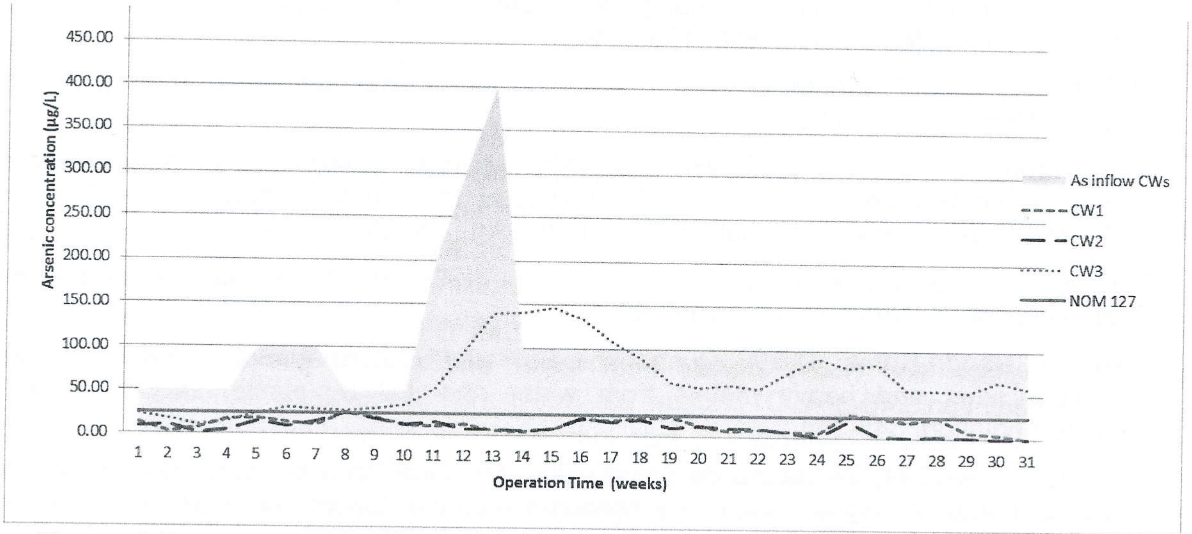


**Figure 1.Removal of As in the prototype units with plants (CW1, CW2) and without plants (W3), considering different concentrations of As in the inlet water.**

### *Remarks*

It was confirmed in this study that artificial wetlands are able to remove arsenic from water; this process can be considered for the treatment of drinking water and for treating water with higher concentrations, such as effluents from reverse osmosis systems and industrial wastewater.

A wetland system built with *Eleocharis macrostachya* has a high resilience to the variation of As concentration in the inlet water. This demonstrates the significance of the plants in the systems, which were essential for the obtainment of a high efficiency of arsenic removal from water.

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***References***


Fitz, W. J. and Wenzel, W.W., 2002, Transformations in the soil-rhizosphere-plant system: fundamentals and potential application to phytoremediation, Biotechnol., 99, 259.

Kadlec, R.H., Knight, R.L., 1996, Treatment Wetlands, CRC Press, Boca Raton, Florida.

Litch, L.A., McCutcheon, S.C., Wolfe, N.L., Carreira, L.H., 1995, Phytoremediation of organic and nutrients contaminants, Environ. Sci. Technol. 29, 318.

Litter, M., Morgada, M. & Bundschuh, J., 2010. Possible treatments for arsenic removal in Latin American waters for human consumption. 158(1105–1118).

Ma, L.Q., Komar, K.M., Tu, C., Zhang, W.H., Cai, Y., Kennelley, E.D.., 2001c, A fern that hyperaccumulates arsenic, Nat., 409, 579.

Meharg, A., 2003, Variation in arsenic accumulation-hyperaccumulation in ferns and their allies, New phytol., 157, 25.

Núñez-Montoya, O. G., Alarcón-Herrera, M.T., Melgoza-Castillo, A., Rodríguez-Almeida, F.A., Royo-Márquez, M.H., 2007, Evaluation of three native species from Chihuahua desert for use in phytoremediation, Terra Latinoam., 25, 35.

Pontius, F.W., Brown, K.G., Chen, J.C., Am, J.., 1994, Health implications of arsenic in drinking water, Water Works Assoc. 86, 52.

Raskin, I., Nanda-Kumar, P.B.A., Dushenkov, S., Salt, D.E., Ensley, B.D., 1994, Removal of radionuclides and heavy metals from water and soil by plants, OECD Document, Bioremediation, 345-354.

NOM-127-SSA-1994, Secretaria de Salud, 2000, Modificación a la Norma Oficial Mexicana, Salud ambiental, Agua para uso y consumo humano. Límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización.

USEPA (United States Environmental Protection Agency). Arsenic treatment technologies for soil, waste and water. Office of solid waste and emergency response. EPA 542-R-02-004-June 2002.

Vymazal, J. and KroPfelova, L., 2008, Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow, Environ. Pollut., 14.

Zhao, F.J., Dunham, S.J., Mc Grath, S.P., 2002, Arsenic hyperaccumulation by different fern species, New phytol., 156, 27.