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Bioaccumulation of Aluminum by *Lemna gibba* L. from Secondary Treated Municipal Wastewater Effluents

Erdal Obek · Ahmet Sasmaz

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Abstract In this study, *Lemna gibba* as a sample aquatic plant was used to remove Al from a municipal secondary waste water effluence. *Lemna gibba* was acclimatized to the effluent in situ. The concentration of Al in the plant samples was examined for 7 days. *Lemna gibba* accumulated 500 µg Al g^{-1} on the first day and reached saturation level with an increase of 100 µg g^{-1} on the second day. The results indicated that *Lemna gibba* can be used as an effective aquatic plant at low costs for the treatment of municipal secondary waste water effluent. It was also noted that the plant should be harvested every 2 days for obtaining maximum efficiency.

Keywords Bioaccumulation · *Lemna gibba* · Duckweed · Aluminum · Secondary treatment · Municipal wastewater

Waste water in different compositions and types from different sources are treated by using various physical, chemical and biological treatment methods. The complete removal of toxic metals from waste water streams by these methods has led to advanced treatment methods. Among those methods, phytoremediation method which is the use of living green plants for in situ risk reduction and/or removal of contaminants from contaminated soil, water, sediments, and air could be an efficient alternative to conventional treatment systems such as precipitation, active carbon adsorption, reverse osmosis, ion exchange etc., especially for small communities, typically rural or suburban areas, due to low treatment and maintenance costs (Solano et al. 2003; Babatunde et al. 2008).

Plants that hyperaccumulate metals have tremendous potential for application in removing of metals in waste waters. *Lemna gibba* is one of the plants used for removing the pollutant metals in waters through phytoremediation method. This plant is widely used in waste water treatment because it accumulates organic and inorganic pollutants (Khellaf and Zerdaoui 2009; Obek 2009; Sasmaz and Obek 2009). Of the common pollutants, Aluminum (Al^{3+}) is found to be one of the most known phytotoxic elements under acidic conditions (Stephan et al. 2008). Al is not a transition metal and cannot catalyze redox reactions. It can result in oxidative damage to major biomolecules (DNA, lipids, proteins) as well as induction of antioxidative defense mechanisms (Exley 2003). It is also a nonessential element for metabolic processes (Fodor 2002). So far, Al has been shown to interfere with uptake and transport of some essential nutrients as well as with cell division in roots, to increase cell wall rigidity (cross-linking pectins), to alter plasma membrane, and to change activities of many enzymes and metabolic pathway involved in repair mechanisms (Rout et al. 2001).

Wetland treatment systems could be used for Al removal but their efficiency for the treatment of Al-rich effluents is unknown. Possible improvements to Al removal through phytoremediation in such ponds would be of interest to the Al refining industry, but present scientific knowledge in this area is very scant (Wieder 1993; Gensemer and Playle 1999). Dissolved Al is less efficiently retained by water management ponds than particulate Al. Phytoremediation could potentially improve the retention of dissolved Al, but there is scarce information on the capacity of aquatic macrophytes to accumulate dissolved Al (Goulet 2005).

E. Obek
Firat University, College of Keban, 23700 Elazig, Turkey

A. Sasmaz (✉)
Department of Geology, Firat University, 23119 Elazig, Turkey
e-mail: asasmaz@firat.edu.tr; eobek@firat.edu.tr

Secondary treated wastewater requires further treatment before being discharged to the surface waters (Upadhyay et al. 2007). Aquatic plants take up and bioaccumulate dissolved metals, and this uptake is normally related to the dissolved free metal ion concentration (Parker and Pedler 1997). Therefore, the objective of this experimental study was to determine the ability of *Lemna gibba* to remove Al from secondary treated municipal wastewater in Elazığ

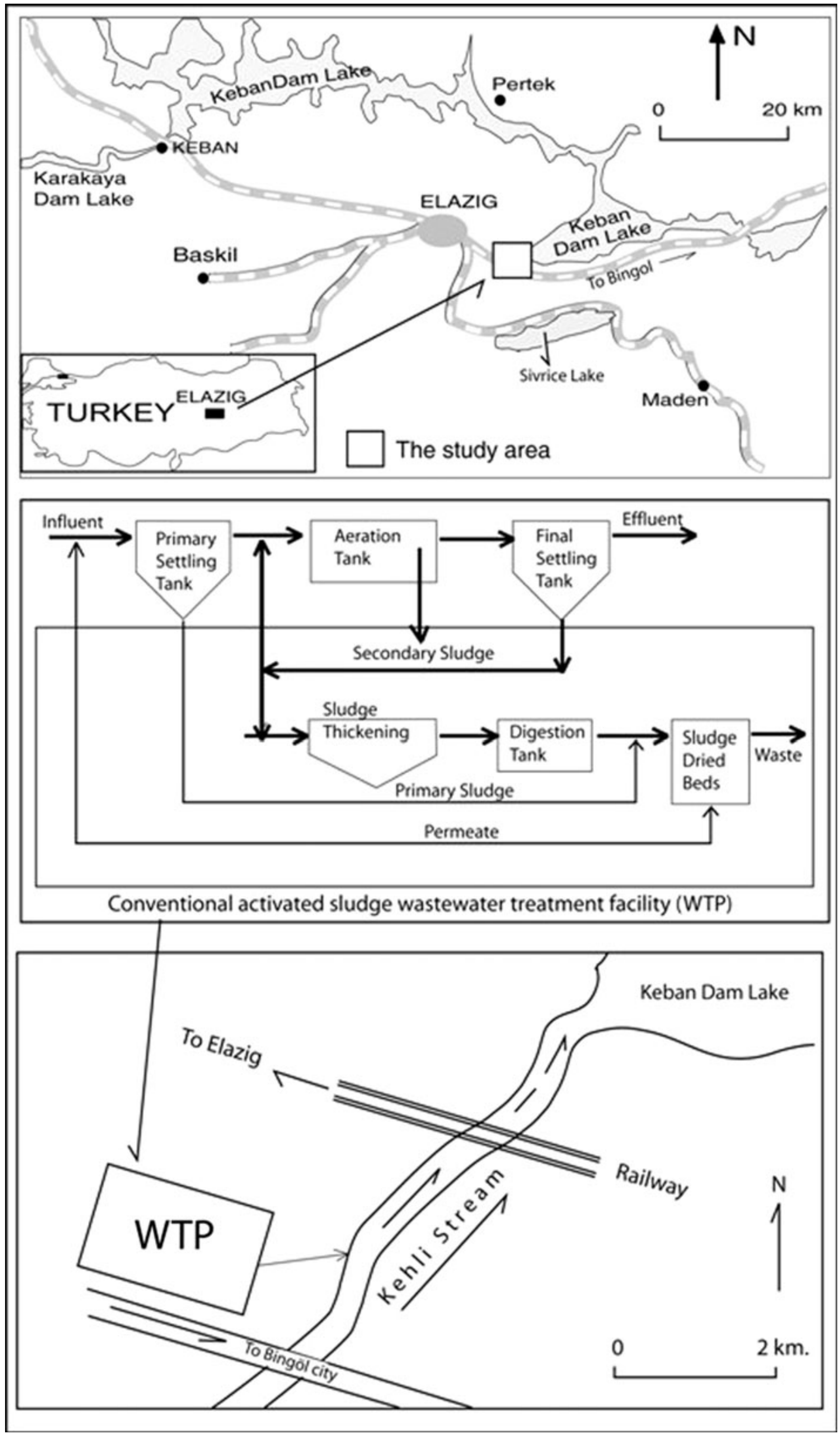

Fig. 1 Map of the study area and flow sheet of the Elazığ municipality wastewater treatment plant

Turkey. The wastewater of Elazig is collected and then treated in the conventional activated sludge process.

Materials and Methods

Contrary to the most of the previous studies carried out in laboratories, in our investigation, an experimental study was carried out in a natural environment. Climatic conditions in the study area during the study period were: mean daily temperature, 24.9 ± 6.8°C; mean daily relative humidity, 31.6 ± 2.8%; mean period of sunny days (h), 12.1 ± 0.4; and mean global radiation, 570.4 ± 19 W m^{-2} (information was provided by the Turkish State Meteorological Service).

During the plant preparation process, *Lemna gibba* was collected from a natural lake in Elazığ during June and July, 2006 (Fig. 1). Within 15–20 min, after collecting the plant, the selected samples (1120 g) were placed into an open container in the effluent of a final settling tank of the Elazig Municipality Wastewater Treatment Plant (this wastewater treatment plant uses a conventional activated sludge process for treating municipal wastewater). The container (45 cm × 75 cm × 35 cm), having the plant material plus water from the lake, was covered with tulle and then completely immersed in the wastewater. For 7 days, approximately 150 g of plant material was daily removed and dried under the atmospheric conditions, and the water samples were taken. The samples were stored at a temperature of 4.0°C.

Procedures in the Standard Methods for the Examination of Water and Wastewater (APHA 1995) were used for the physicochemical analysis of the samples, and the trace elements were quantified by the atomic absorption method (Perkin–Elmer). The air-dried plant samples were then dried in a drying oven at 103°C for 24 h and then ashed at 480°C for 4 h. These ashed samples (1.21 g of ashed plant material from approximately 3.80 g of dried plant material) were taken by using hand mortars, labeled, and sent to Canada for analysis. Ashed samples were digested in HNO_3 for 1 h and then in a mixture of $HCl\text{-}HNO_3\text{-}H_2O$ for 1 h (6 mL of the mixture of 1/1/1 was used for 1.0 g ash) at 95°C. Acid was added to the water samples. The samples were analyzed by using inductively coupled plasma mass spectroscopy (ICP/MS; Perkin–Elmer ELAN 9000) at Acme Analytical Laboratories Ltd. in Canada (http://www.acmelab.com/cfm/index.cfm). Acme is currently registered with ISO 9001:2000 accreditation.

Table 1 Physicochemical characteristics of wastewater in the secondary clarifier and in natural water

Parameter	Unit	Wastewater	Natural water
Temperature	°C	17.60 ± 0.50	19.30 ± 0.01
pH		7.67 ± 0.10	7.10 ± 0.10
DO	(μg/L)	3.75 ± 0.1	6.42 ± 0.1
COD	(μg/L)	35.00 ± 3.00	8.30 ± 2.00
NO_2^-N	(μg/L)	0.08 ± 0.01	0.20 ± 0.01
NO_3^-N	(μg/L)	0.60 ± 0.01	2.70 ± 0.01
PO_4^{-3}–P	(μg/L)	>5.00	0.16
NH_4^+–N	(μg/L)	<0.04	0.93 ± 0.30
P	(μg/L)	4796	161
Ca	(μg/L)	86590	83114
K	(μg/L)	17068	9160
Na	(μg/L)	109551	12109
Mg	(μg/L)	29428	9090
Fe	(μg/L)	<100	66
Al	(mg/L)	48 ± 1	169

Results and Discussion

The results of physicochemical analyses of secondary treated municipal wastewater effluence are given in Table 1. Table 2 displays the percentage values of some nutrients and Al amount in μg/g accumulated by *Lemna gibba* from the secondary wastewater effluence. As shown in Table 2, maximum accumulation was recorded on the first day. A direct comparison of the results obtained in the

Table 2 Aluminum accumulation per day by *Lemna gibba*

Parameter	Before study	After study						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
P (%)	0.66	0.53	0.61	0.54	0.68	0.74	0.74	0.63
Ca (%)	3.66	3.41	4.3	3.57	4.01	4.27	4.02	3.84
K (%)	2.43	1.89	2.03	1.66	1.87	1.66	1.86	1.81
Na (%)	0.59	0.32	0.37	0.29	0.35	0.32	0.31	0.30
Mg (%)	0.38	0.30	0.36	0.31	0.38	0.38	0.37	0.35
Fe (%)	0.03	0.09	0.11	0.09	0.10	0.13	0.11	0.09
Al (μg/g)	167	667	767	633	700	767	700	467

previous studies with our results is not possible. For example, 54% removal of Al from acid mine drainage was achieved by wetland treatment systems (Wieder 1993). In a preliminary experiment, Gallon et al. (2004) exposed aquatic macrophytes hydroponically to synthetic Al effluents and observed that the studied species removed about 59%–85% of the dissolved Al present in the water at the beginning of the experiment (Gallon et al. 2004). *Lemna minor* had the highest Al uptake rate of (0.8–17 mg Al g^{-1} d^{-1}) in another study (Goulet et al. 2005). Havas (1986) tabulated Al bioaccumulation data for US and Canadian lakes and observed that macrophytes accumulated less than 40–32,000 μg Al g^{-1} dry weight. However, our study indicated that *Lemna gibba* has a capacity of accumulation of 500 μg Al g^{-1} on the first day and this capacity increased 100 μg g^{-1} on the second day. Such a result demonstrates that *Lemna gibba* can be used efficiently for Al removal for 2 days. In this sense, metal accumulation capacity could be attributed to the differences in metal accumulation and metabolic activities in growth in natural living environment (Upadhyay et al. 2007). It was also observed that a two-day harvest of *Lemna gibba* can provide maximum efficiency as stated by Obek (2009) and Sasmaz and Obek (2009).

Using aquatic plants for the removal of pollutant metals from wastewater by accumulating them within the plant is a cost effective and practical treatment method. Among the others, *Limna gibba* is a promising aquatic plant. This study proved that *Limna gibba* can be used to remove Al from municipal secondary waste water effluence as an advanced treatment (Al removal) method in a natural setting. The findings demonstrated that *Lemna gibba* has a capacity of the highest 500 μg g^{-1} of Al accumulation within the first day of the treatment, and it should be harvested every 2 days for maximum efficiency since it reaches saturation level at the end of the second day.

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