

# Removal of Arsenic from Drinking Water by Water Hyacinths (*Eichhornia crassipes*)

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**ABSTRACT:** In Bangladesh, people drink groundwater that has arsenic levels high enough to eventually cause death. Phytoremediation, the use of plants to remove pollutants, has been used to remove metals such as arsenic. Other scientists have tested the ability of water hyacinths (*Eichhornia crassipes*) to remove arsenic from water, with varying results. The purpose of my project was to determine if it is practical to use water hyacinths to remove arsenic from water.

I did three experiments. First, I tried to maximize the number of times the same water hyacinths could reduce the arsenic concentration in water. I grew water hyacinths in 300 ppb arsenic-contaminated water in a greenhouse. I added light and heat to try to increase their arsenic removal abilities. I found that the same water hyacinth plants could remove arsenic seven times, but only twice to the drinking water standard.

Second, I digested plant samples (for outside lab testing) to determine where within the plant arsenic is stored to help understand the removal mechanism. The results showed that the plants store the most arsenic in their bladders (which are for floatation) and the least in their roots.

Third, I digested the dead plant debris with hydrogen peroxide to attempt to remove the arsenic, to minimize the volume of waste generated. I tested the extracted liquid myself using ICP. The hydrogen peroxide digestion removed a significant portion of arsenic from the solids, which could allow most of the arsenic to be precipitated efficiently from the liquid for disposal.

**KEYWORDS:** *Eichhornia crassipes* / water hyacinth, phytoremediation, arsenic, Bangladesh, arsenic removal.

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## 1. INTRODUCTION

The overall goal of my project was to determine whether or not it is practical to use water hyacinths to remove arsenic from drinking water in Bangladesh. The first goal of my project this year was to see if I could increase the number of times the same water hyacinths could reduce the arsenic level to a safe drinking water standard by increasing light and temperature of the water hyacinths' immediate environment (in the greenhouse). The second goal of my project was to better understand how water hyacinths remove arsenic by determining where the plants store the arsenic so that I could work to optimize the plants' arsenic removal potential. The third goal of my project was to find a disposal method for the water hyacinths by using a hydrogen peroxide digestion to get the arsenic out of the dead plant tissue.

Poisoning from arsenic in groundwater used for drinking is a very serious problem in many regions of the world. Up to fifty million people worldwide may be severely affected by arsenic in their drinking water. First they develop sores on their hands and feet, and then they eventually die, usually due to internal cancer [3]. Arsenic occurs naturally throughout the world because arsenic is in the earth's crust; however, in some regions, such as Bangladesh, the western United States, Mexico, northern Chile, Argentina, Hungary, Romania, Mongolia, Taiwan, Vietnam, Thailand, Nepal, and India, certain geological formations contain higher levels of arsenic and therefore cause the groundwater aquifers to have higher arsenic levels [10]. It has been determined that in Bangladesh about 30% of the tubewells installed in shallow aquifers have arsenic levels over 50 parts per billion (ppb), which is the Bangladesh government's standard for drinking water. The World Health Organization and the United States Environmental Protection Agency (US EPA) have set a drinking water standard of 10 ppb. Five to ten percent of the tubewells in Bangladesh have arsenic levels over 300 ppb [3].

## **General Information on Phytoremediation**

Phytoremediation is the process of using plants to remove pollutants from soil or water [9]. Plants that phytoremediate can be divided into two categories: excluders and non-excluders. Excluders are plants that either keep pollutants, such as metals, completely out of the plant or keep the pollutants out of the top part of the plant. Non-excluders (also known as accumulators) are plants that allow pollutants in and then transport the pollutants to the top part of the plant [12]. Hyperaccumulators are plants that accumulate metals in higher concentrations than the concentrations in the soil or water in which they are living.

## **Phytoremediation by Water Hyacinths**

Water hyacinths are free-floating aqueous weeds [5] that multiply very quickly [8]. They have fibrous roots and obtain all of their nutrients from the water. Water hyacinths are common in Bangladesh [8], a fact that is important for this project.

Several scientists have looked at water hyacinths' ability to remove arsenic from water, with somewhat differing results. Some studies have reported water hyacinths to be very effective at removing arsenic from contaminated water. Misbahuddin and Fariduddin found that just the roots of water hyacinths removed 81% from a 400 ppb arsenic solution. The entire water hyacinth plant (roots, leaves, stems, etc.) was reported in the same study to have removed one hundred percent of the arsenic, and to have done so in only three to six hours [8]. Other scientists have reported that water hyacinths do not have very high arsenic removal capabilities. Zhu, Zayed, Qian, Souza, and Terry reported that water hyacinths do not accumulate arsenic well and that most of the arsenic they take up is stored in their roots [14]. Zhu, Lytle, and Terry reported that water hyacinths convert a large portion of the arsenate they remove to the more toxic form of arsenic, arsenite, within the plant itself [13].

## **Mechanisms of Arsenic Removal in Other Plants**

When a plant takes up arsenic, there are two things it can do with the arsenic: it can store the arsenic in the roots, or it can transport the arsenic to its above ground/water parts. Arsenic

accumulation in the roots of a plant can be an arsenic exclusion strategy used by non-accumulators. When most of the arsenic ends up in the top part of the plant, however, that means the plant has an efficient root to top transport system. This efficient transport can lead to hyperaccumulation [12].

According to Knudson, Meikle, and DeLuca, some plants take up arsenic through their phosphate uptake system [7]. This would make sense because in a phosphate compound ( $\text{PO}_4^{3-}$ ), the phosphorus has an oxidation number of 5+. In a metaarsenate ion ( $\text{AsO}_3^{1-}$ ), the arsenic has an oxidation number of 5+. Moreover, arsenic is right below phosphorus on the periodic table of the elements, and elements in the same period tend to behave similarly, so it is quite possible that plants cannot tell the difference between phosphate and arsenate. This lack of ability to distinguish could lead to accidental uptake of arsenate by plants as they try to take up phosphate.

Zhang, Cai, Tu, and Ma looked at the different types of arsenic in the brake fern. They found only arsenate (As V) and arsenite (As III) in the plant. They found 60-74% of the arsenic in the fronds was in the form of arsenite, but only 8.3% of the arsenic in the roots was in the arsenite form. The soil started with equal amounts of arsenate and arsenic, but after eighteen weeks of the experiment, most of the arsenic left in the soil was in the arsenite form, meaning that the plant had taken up most of the arsenate, probably through the phosphate system. Based on these data, the researchers believe that the plant reduced the As (V) in the arsenate to free As III as part of its detoxification system. Generally, arsenite is usually more toxic to organisms; however, they believe that exposure of the ferns to arsenic induces thiols, sulfur-containing organic ligands known as chelators, that complex the arsenite to keep the arsenic from harming the plant [12].

### **Arsenic Digestion**

Kim, Ra, Cong, and Song experimented with using hydrogen peroxide to remove chromium, copper, and arsenic from copper chromium arsenate-treated wood. They found that 5% hydrogen peroxide at 60° Celsius for thirty-six hours extracted all of the arsenic from the wood [6]. Therefore, my last purpose was to find a plant disposal method that could be used in Bangladesh. I tested this hydrogen peroxide method to determine if it would remove all of the arsenic from the plant debris.

## **Potential Use of Water Hyacinths in Bangladesh**

Several studies suggest that it may be possible to use water hyacinths effectively to remove the arsenic from the drinking water that is poisoning the people of Bangladesh [5, 13, 14]. Thus, water hyacinths may be a practical solution because using them as a treatment method has very little cost, given that water hyacinths grow naturally in the ponds in Bangladesh. It has been suggested that a treatment technique would be to have groundwater users draw the water from their tubewells into a large container, known as a chari, that the farmers use for animal feed. The water hyacinths would then float in the water for a day and remove the arsenic before the water is drained into another vessel for use. Then, the chari would be re-filled to treat the next day's supply of water [8].

## **2. SUMMARY OF LAST YEAR'S RESEARCH**

Under the conditions of my experiment last year, the same water hyacinths (a total of 1711 grams) reduced the arsenic level of 20 L of a typical Bangladeshi well water concentration significantly for seven trials. These plants were maintained in an approximately 16° Celsius greenhouse, which is much colder than a typical Bangladeshi temperature and below the recommended water temperature for the water hyacinths of 23° Celsius [11]. I also attempted to determine the arsenic concentration in the upper part of the plant as compared to the lower part of the plant. I was able to determine that the arsenic was stored throughout the plant, but I was unable to measure the exact concentrations in specific parts of the plant.

## **3. PART I: OPTIMIZING ARSENIC REMOVAL BY WATER HYACINTHS**

### **Materials and Methods**

The first part of my experiment was to determine whether adding light and heat to the plants' environment would improve their arsenic uptake. I assessed plant health before and after arsenic exposure by looking at both the plants' visual health and their weight. I qualitatively

assessed plant health on a scale of one to five: “1” indicated that all of the leaves and stems were brown and “5” reflected a condition where all of the leaves and stems were all green. I weighed the plants at the same time as I assessed their health. It was recorded as a wet weight.

For the control, I placed twenty-four identified water hyacinths (1187 total grams, wet) in a plastic tub with 20 L of tap water. The arsenic tub had twenty-one identified plants (1194 total grams, wet) in 20 L of tap water. Then I placed the tubs in the greenhouse. I hung grow lights above the tubs and used a timer to provide a sixteen-hour light period each day. I installed aquarium heaters in the tubs and adjusted them so that the temperature of the tubs was about 23° Celsius (75° Fahrenheit).

Using arsenate and arsenite powder [1] I created a 300 ppm (as arsenic) arsenite solution and a 300 ppm (as arsenic) arsenate solution in distilled water. I had to add sodium hydroxide to make the arsenite powder dissolve, and then I neutralized the solution with acetic acid. For the control, I prepared a sodium hydroxide-acetic acid solution with the same concentrations that I had added to the arsenite solution. I added 10 mL of the arsenite solution and 10 mL of the arsenate solution to the arsenic tub to create 20 L of 150 ppb arsenite (as arsenic) and 150 ppb arsenate (as arsenic) for a total of 300 ppb (as arsenic) arsenic concentration. Then I stirred the water well. I added 10 mL of control sodium hydroxide-acetic acid solution to the control tub to match the sodium acetate concentration in the arsenic tub and stirred well.

I measured the arsenic levels of the water on days when I had supervised access to the lab (Tuesday through Friday), using a Hach colorimetric arsenic test kit, following the instructions.

On testing days, I started the sampling process by stirring the arsenic tub. Then I took a 50 mL sample and tested the arsenic level using the colorimetric test kit. From that measurement of the arsenic concentration in the tub, I then calculated and added the amount of arsenite and arsenate solution I needed to add to raise the arsenic level back up to 300 ppb, always using equal amounts of arsenite and arsenate solution. Then I measured out the same amount of sodium hydroxide-acetic acid solution to add to the control tub as the amount of arsenite solution added to the arsenic tub. I added the solutions to the tubs and stirred well. I repeated these measurements and additions of more arsenic until the arsenic level was no longer reduced below 300 ppb after at least 24 hours. As needed, I re-filled the tubs with water to maintain 20 L of water.

## Results

Arsenic removals are given in Table 1.

**Table 1: Arsenic Removal**

Date	Starting Arsenic Concentration (ppb)	Ending Arsenic Concentration (ppb)	Meets EPA's 10 ppb Drinking Water Standard?	Meets Government of Bangladesh's 50 ppb Drinking Water Standard?
8/7/2006	300	120	NO	NO
<i>Break in Testing</i>				
10/4/2005	no arsenic added	10	YES	YES
<i>Break in Testing</i>				
1/18/2006	300	70	NO	NO
1/19/2006	300	70	NO	NO
1/20/2006	300	70	NO	NO
<i>Break in Testing</i>				
1/24/2006	300	70	NO	NO
1/25/2006	300	70	NO	NO
1/26/2006	300	0	YES	YES
<i>Break in Testing</i>				
1/31/2006	300	300	NO	NO

## Discussion of Results

I found that the same water hyacinths removed arsenic from water with a starting arsenic level of 300 ppb a total of seven times. The first trial for these plants was not under the experimental conditions described above, but it was during the summer when I hoped to take advantage of the warmer temperatures and sunny days. Although the plants initially only reduced the arsenic level of the water to 120 ppb, by two months later, the plants had reduced the arsenic concentration to 10 ppb, which meets the U.S. EPA's arsenic drinking water standard of 10 ppb [4].

The next trials were conducted in the greenhouse under the experimental conditions described above. The plants reduced the arsenic in the water from 300 ppb to 70 ppb (0 ppb the last time) six times. The air temperature in the greenhouse ranged from about 17-24° Celsius.

The water temperature was about 21° Celsius most of the time. In addition to warmer temperatures, the plants had sixteen hours of direct light each day from a hanging grow light. I knew that the water hyacinths had stopped removing arsenic when the arsenic concentration of the water remained at 300 ppb after almost a week after adding arsenic.

This year the mass of water hyacinths I had was lower than last year. Last year there were 1711 grams (wet) of water hyacinths in the 20 L of arsenic water. This year there were only 1194 grams (wet) of water hyacinths in 20 L of arsenic water. It is quite possible that, if the mass of water hyacinths had been higher this year, they would have been able to remove more arsenic, both in terms of reducing the arsenic concentration lower each trial and being effective for more trials.

When the plants stopped removing arsenic, I assessed their health. The control plants were very green. The whole top parts of the plants exposed to arsenic were beginning to die and turn brown and a paler green. Assessing with my 1-5 criteria, there was a statistically difference in the health of the two sets of plants at the end of the experiment according to an ANOVA (Analysis of Variance) test at a 95% confidence level.

The control plants gained more weight than the arsenic plants; however, there was not a statistically significant difference at a 95% confidence level. In addition, I noticed that, after arsenic exposure, that most of the arsenic plants had a much smaller root mass than the control plants. A common gardening rule for fertilizer is that phosphorus is for roots. So, if the arsenic was harming the phosphate uptake system, it may have been harming the roots the most.

### **Sources of Error and Possible Continuations**

One potential source of error in my experiment arose because the method I used for testing the arsenic levels was a field colorimetric test kit, which only indicated the following levels: 0, 10, 30, 50, 70, 300, and 500 ppb. This was probably not sufficiently precise for the experiment. For example, when I read a level of 300 ppb, the observed color was closer to 300 ppb than 70 ppb, but could have been somewhere in between. I estimated between the colors as best as I could when needed.

The first thing I will do to continue this part of my project is to use an arsenic solution without acetate ions to see if that increases the water hyacinths' ability to remove arsenic,

because the presence of an acetate ion (which was in my arsenite solution) was found to reduce the ability of dead water hyacinth roots to remove uranium (VI) by 66% [2]. Secondly, I will try changing pH, because other scientists have found that plants remove more metals at different pH. Thirdly, I would like to continue testing with one plant exposed to arsenic that remained unusually healthy, and its offspring, to see if they have adapted to become capable of removing more arsenic. I would also, after the uptake test, determine in which parts of the plant the arsenic is stored to see if these plants are doing something different with the arsenic than the other plants. If all else fails, I will increase the grams of water hyacinths per liter of water.

#### **4. PART II: UNDERSTANDING HOW WATER HYACINTHS REMOVE ARSENIC**

##### **Materials and Methods**

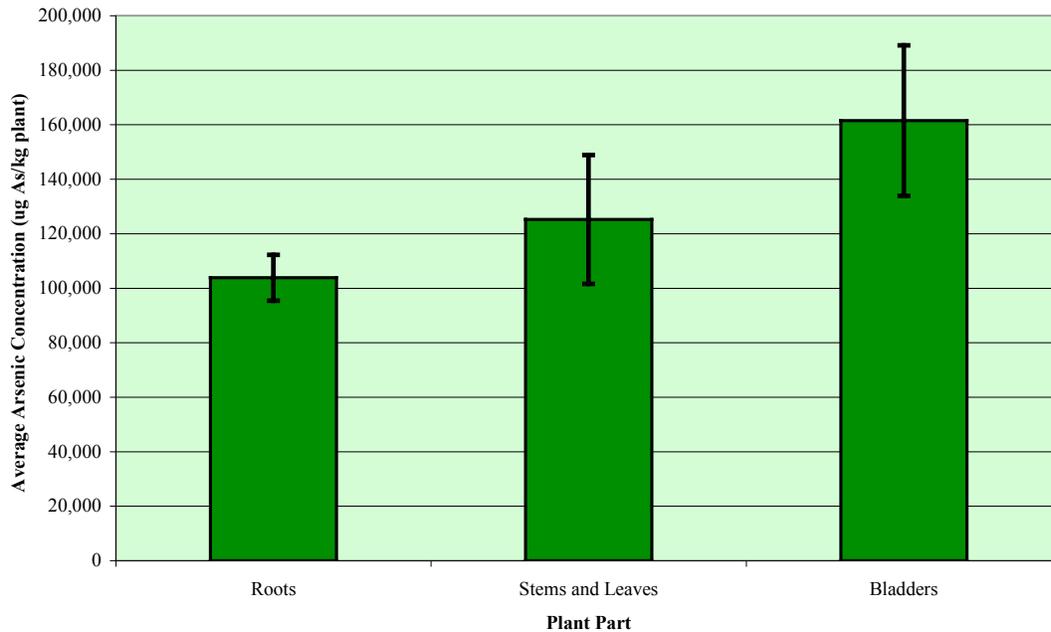
I tested where within the plants the arsenic had accumulated by first preparing five samples of each of the different parts of the plants (stems and leaves, bladders, and roots). I separated each dead, dried arsenic plant from last year's uptake study into roots, stems and leaves, and bladders. I analyzed the samples by Inductively Coupled Plasma analysis, which required that the solid samples be digested into a liquid solution using a modified procedure based on Zhang, Cai, Tu, and Ma [12]. I dried the plant parts in an oven for twenty-four hours at about 70° Celsius. I then ground up the samples using a mortar and pestle. I weighed out approximated 0.01 grams of sample on a scale with four decimal places and recorded the actual weight. I put the weighed sample in a 50 mL beaker in a sand bath. Three samples of each plant part (stems and leaves, bladders, and roots) were prepared. I then digested the samples in a hood by heating the sand bath up to 150° Celsius and having my teacher add 10 mL of concentrated nitric acid. I added a little bit of distilled water to the samples as needed to keep them from boiling dry. After 1 hour, my teacher added 2 mL of 30% hydrogen peroxide to each sample. After another 30 minutes, I turned off the heat. When the samples had cooled, I brought them up to volume in 100 mL volumetric flask with distilled water. I then went to Oregon Steel Mills metallurgy lab where I tested the arsenic concentration using Inductively Coupled Plasma after calibrating with help from the chemist there using a blank, 1 ppm standard (with nitric acid), 10 ppm standard (with nitric acid), and a 100 ppm standard (with nitric acid). However, I discovered

that the detection limit achievable by the Inductively Coupled Plasma instrument was not low enough, so I brought the digested samples to North Creek Analytical Lab to be analyzed using their Inductively Coupled Plasma-Mass Spectrometry.

## Results

Average arsenic concentrations in different parts of the plant are shown in Figure 1.

**Figure 1: Average Arsenic Concentrations in Different Parts of the Plant**



Note: The error bars shown are 95% confidence interval error bars.

## Discussion of Results

I found the highest arsenic concentration in the bladders of the water hyacinths, 162,000 ppb. The water hyacinths may move the arsenic to their bladders to keep it from harming photosynthesizing portions of the plant. The stems and leaves had the second highest average

arsenic concentration at 125,000 ppb. The roots had the lowest average arsenic concentration, at 104,000 ppb. Using an ANOVA analysis of variance test in EXCEL, I found that the difference between the average arsenic concentration in the roots and the average arsenic concentration in the bladders was statistically significantly at a 95% confidence level. This means that the water hyacinths are not arsenic excluders because they are transporting the arsenic to the top part of the plant.

I also calculated the bioconcentration factors for the different parts of the plant. The bioconcentration factor is the ppb arsenic in the plants divided by the ppb arsenic in the water surrounding the plants. The bioconcentration factors for the bladders, stems and leaves, and roots were: 538, 417, and 346, respectively. Because the bioconcentration factors were greater than one, water hyacinths are arsenic hyperaccumulators by definition.

### **Sources of Error and Possible Continuations**

There was some error in my separation of the different plant parts because, by the time I separated them, all of the plants had dried together, making it hard to separate the different plant parts.

To test the hypothesis that water hyacinths remove arsenic the same way they remove phosphate, and therefore would favor uptake of the arsenate, As (V), in continuing this experiment I can give separate plants just arsenate and others just arsenite to see if they remove more of the arsenic in the arsenate form.

Another thing that I can do is continue researching the mechanism the plants use to uptake arsenic and phosphate to see if there is something I can do to increase the uptake, such as adjusting pH. The other piece of phytoremediation is what the plant does with the arsenic once it has transported the arsenic to the top part of the plant. So, I will also do more research on the ligands that plants use to sequester arsenic and see if there is anything I can do to increase that process, thereby increasing the plants' tolerance of arsenic.

## **5. PART III: REMOVING ARSENIC FROM PLANT DEBRIS FOR DISPOSAL**

### **Materials and Methods**

For this part of my project, I first took the remaining dried roots, stems, and leaves from last year's study and prepared five samples of the combination for neutron activation analysis to determine my starting arsenic concentration. I prepared samples for neutron activation analysis by placing a weighed amount of sample into a clean vial that I then sealed. After preparing the sample vials according to the instructions from Reed College, I sent them to Reed College for neutron activation analysis. After the samples had been placed inside the reactor and their emitted gamma rays were counted, I went to Reed College to read the relevant emission peaks. I selected the arsenic peak (559 keV), and the computer program calculated the area under the peak. I put that in a spreadsheet that calculated the arsenic concentration based on the gamma ray emissions, the half-life of arsenic, the amount of time that had passed since the sample had come out of the reactor and begun decaying, and the weight of the sample. I also prepared samples for Inductively Coupled Plasma using the procedures described above.

To test the extraction technique, I extracted the arsenic from the remaining dried plant debris using 5% hydrogen peroxide. Working in a hood, I put two grams of dried plant in a 100 ml volumetric flask and added 40 ml 5% hydrogen peroxide. I put the flask on a magnetic stirrer/heat plate. The flask was stirred using the magnetic stirrer for three days. I adjusted the heat until the solution was at about 60° C [6] and attempted to maintain this temperature throughout the three days. I then filtered this through coffee filters and prepared the solids for neutron activation analysis (see procedure above). I also analyzed the liquids left after the digestion process (after bringing them up to volume in 100 mL volumetric flask with distilled water) with Inductively Coupled Plasma analysis as discussed above. These concentrations were above the detection limit of the instrument, so I did not need to send these samples for the Inductively Coupled Plasma-Mass Spectrometry analysis.

## Results

Results from digestion of 2 g of plant debris are given in Table 2.

	<b>µg arsenic</b>	<b>Percent of arsenic in liquid or solid</b>	<b>Testing method</b>
<b>Average TOTAL before digestion</b>	<b>156</b>		<b>NAA</b>
<b>Average TOTAL before digestion</b>	<b>173</b>		<b>AA</b>
<b>Average SOLIDS after H<sub>2</sub>O<sub>2</sub> digestion</b>			
<b>Average SOLIDS after H<sub>2</sub>O<sub>2</sub> digestion</b>	<b>73</b>	<b>78</b>	<b>NAA</b>
<b>Average LIQUIDS after H<sub>2</sub>O<sub>2</sub> digestion</b>	<b>21.2</b>	<b>22</b>	<b>ICP</b>
<b>Sum</b>	<b>95</b>		
<b>Average SOLIDS after control (H<sub>2</sub>O)</b>			
<b>Average SOLIDS after control (H<sub>2</sub>O)</b>	<b>203</b>	<b>96</b>	<b>NAA</b>
<b>Average LIQUIDS after control (H<sub>2</sub>O)</b>	<b>9.3</b>	<b>4</b>	<b>ICP</b>
<b>Sum</b>	<b>212</b>		

**Table 2. Digestion of 2 g of plant debris.**

## Discussion of Results

I consider the data I have from neutron activation analysis imprecise because, on average, my 300,000 ppb standards had a raw average initial arsenic concentration reading of 156,000 ppb (I adjusted my data based on this) and a standard deviation of more than 43,000. Even though these data are imprecise, they are still useful for looking at trends. These data show that there

was much less arsenic left in the solids after the hydrogen peroxide digestion as compared to the solids after soaking in water. This shows that the hydrogen peroxide digestion method did remove some of the arsenic from the solids, but not all of it. The Inductively Coupled Plasma data supports this, showing a higher arsenic concentration in the liquids after the hydrogen peroxide digestion than in the water the plants soaked in for the control.

### **Sources of Error and Possible Continuations**

There was a large source of error in the analysis of the arsenic concentration in water hyacinths. I know this because the data from the neutron activation analysis had very large standard deviations within samples from the same part of the plant. I believe that this source of error was caused by interference from sodium because the half-life of sodium is about the same length as the half-life of arsenic. When high amounts of sodium are present, it tends show up everywhere in the gamma ray counts, interfering with the peaks that should be for other elements, such as arsenic. Another source of error was in the hydrogen peroxide digestion procedure itself. It was hard to keep the temperature of the samples at 60° Celsius constantly. The temperatures got down to about 30° Celsius for one day, at least.

To continue this experiment I will repeat this experiment in a sand bath to ensure a constant temperature of 60° Celsius. If all of the arsenic still is not removed, I will use stronger concentrations of hydrogen peroxide to see if stronger concentrations will remove all of the arsenic. Also, I will test digested samples of the solids using Inductively Coupled Plasma for more accurate data. Finally, I plan on testing to see if I can precipitate the arsenic out of the liquid after the hydrogen peroxide digestion using sodium sulfide.

## **6. CONCLUSIONS**

I found that the mass of water hyacinths I used (1194 g/ 20 L) could remove arsenic a total of seven times, but only down to the U.S. EPA's drinking water standard of 10 ppb and the Government of Bangladesh's drinking water standard of 50 ppb twice. Based on my data from last year, I believe this may be improved upon by increasing the mass of plants per liter. I found that the water hyacinths store most of the arsenic in their bladders, followed by their stems and

leaves, followed by their roots. This shows that the water hyacinths are transporting the arsenic up through their roots to the stems and then out to the bladders, which are not an actively photosynthesizing part of the plant. Finally, there was a trend showing that the hydrogen peroxide digestion could be successful in removing arsenic from the plant debris solids that would need to be disposed. I believe that there are still many variables that I can change so that water hyacinths could be used to remove arsenic from water.

## **7. ABBREVIATIONS AND ACRONYMS**

ANOVA: Analysis of Variance, a statistical test

ICP: Inductively Coupled Plasma

ICP-MS: Inductively Coupled Plasma-Mass Spectrometry

NAA: Neutron Activation Analysis

ppb: parts per billion ( g/L)

ppm: parts per million (mg/L)

U.S. EPA: United States Environmental Protection Agency

WHO: World Health Organization

## **8. ACKNOWLEDGMENTS**

### **Credits**

I would like to thank Mr. Stephen Franz and the reactor staff at Reed College for using neutron activation analysis to analyze some of my plant samples, and then for showing me how to interpret the data. I would like to thank Mr. Bob Marx, chemist at Oregon Steel Mills, who gave up his time to help me conduct the Inductively Coupled Plasma analysis on my samples. I would like to thank North Creek Analytical Lab for analyzing my samples when the other two methods did not work. Finally, I would like to thank my science teacher Rosa Hemphill for her suggestions and supervision while I was working on my project.

### Author

In school, my favorite subjects are chemistry, Spanish, and ceramics. After school, I play junior varsity soccer in the fall and varsity tennis in the spring. During the winter and summer, I combine two of my passions, Spanish language and community service, by tutoring English Language Learners at a local elementary school. I chair the Student Advisory Council that helps run the tutoring by recruiting and training new tutors and helping administer the program. I am also involved in my church community. In college, I hope to study chemistry, environmental engineering, and Spanish. Inspired by my seventh grade Spanish teacher, I want to join the Peace Corps after college and volunteer in a Spanish-speaking country, especially doing something related to water.

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